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Erosion Control Methods for Army Training Land Rehabilitation: Survey of Current Technology

by
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This report is a comprehensive summary of erosion control technology which classifies and briefly discusses current methods, materials, and structures. Greater demands are being made on Army training lands, making them more vulnerable to damage from erosion. Managers of these lands can intervene in erosion processes using appropriate erosion control strategies. These methods can preserve the land's capability to support training activities.

Erosion control measures are classified here according to their roles in disrupting erosion: soil stabilization, runoff management, and sediment control. Within each of these categories, engineering technologies for erosion control are identified in the areas of landforming, materials, and structures. The information given is brief and general; for specifics the reader must consult the technical references. Future reports will develop guidance to help planners identify erosion problems and select appropriate and cost-effective control measures.

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FOREWORD

This work was done for the Office of the Chief of Engineers (OCE) under project 4A162720A896, "Environmental Quality Technology"; Task Area A, "Installation Environmental Management"; Work Unit 047, "Physical Structural Erosion Control for Training Land Rehabilitation." The OCE Technical Monitor was Mr. D. Bandel (DAEN-ZCF-B).

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COL Norman C. Hintz is Commander and Director of the Laboratory and Dr. L. R. Shaffer is Technical Director.

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EROSION CONTROL METHODS FOR ARMY TRAINING LAND REHABILITATION: SURVEY OF CURRENT TECHNOLOGY

1 INTRODUCTION

Background

The purpose of Army training lands is to provide a realistic training environment for developing a superior combat-ready force. These lands must accurately simulate battlefield conditions and provide tactical concealment to allow realistic troop training.

Greater demands are being placed upon Army training lands as force modernization programs using more mobile weapon systems operate over larger areas. More land is being used, and it is used more intensively. Thus, there is a growing need to maintain and improve the environmental integrity of training lands. They should be viewed as a resource which must be managed with foresight to provide training realism and maximum utility for present Army needs, while ensuring their capability to support future Army training missions.

The increasingly high soil erosion rates caused by training activities indicate increasing land degradation, which results in qualitative losses that diminish the realism of the environment and in quantitative losses which reduce the land resources available for current and future activities.

Land degradation (commonly characterized by such erosion features as slope instability, ruts, mud, dust, rill erosion, and gullies) directly affects the training mission. Loss of vegetative cover for tactical concealment detracts from training realism, while slope instability, mud, dust, ruts, and gullies impede training activities and reduce the total area available to support them. If the adverse effects of training continue to increase without a corresponding increase in land maintenance, vast areas of Army training lands will degrade to a condition that will no longer support training activities. Measures must be taken to mitigate the effects of training activities (Figure 1).

A research effort has begun that will provide managers of Army training lands with information and guidelines that will help them (1) identify physical land degradation problems, (2) identify the strategy required to solve those problems, and (3) select appropriate, cost-effective, specific control measures for realistic achievements that are consistent with mission requirements and environmental quality.

Objective

The objective of this study was to compile a comprehensive summary of current methods, materials, and structures used in the application of engineering technology for erosion control.

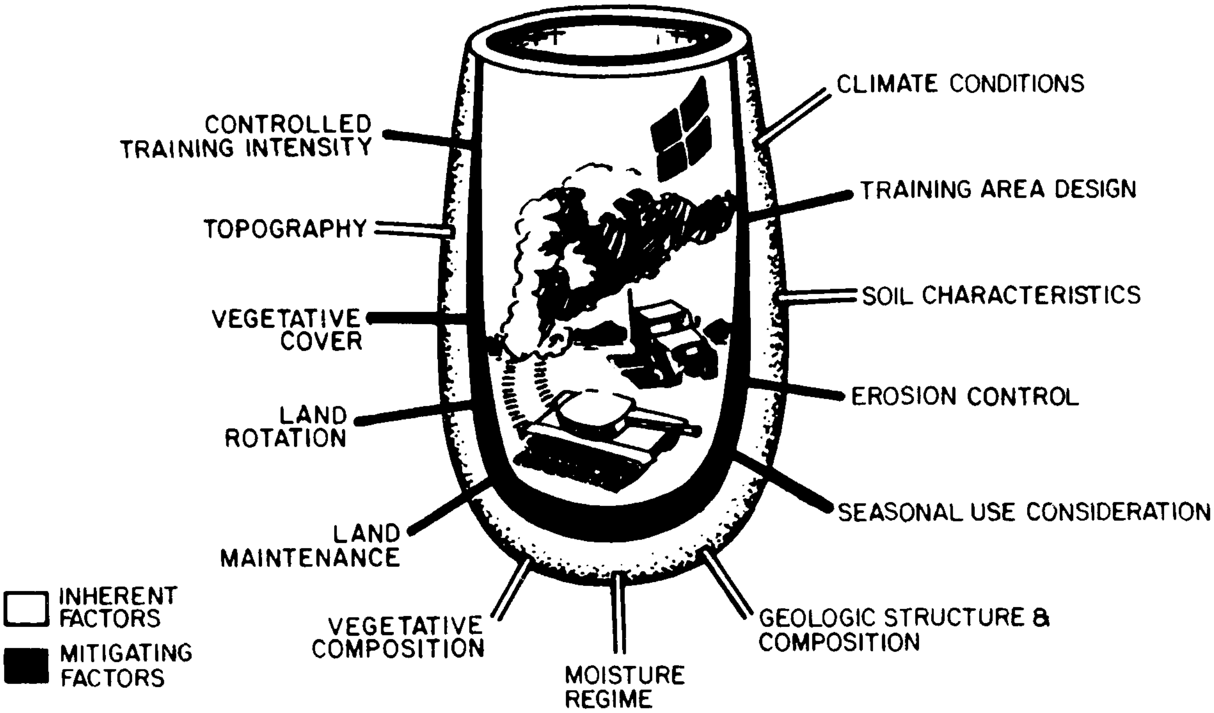


Figure 1. Factors affecting Army training land carrying capacity for training activities.

Approach

Erosion control measures are classified on the basis of how they interrupt erosion processes, whether by providing soil stabilization, runoff management, or sediment control. These classes correspond respectively to the three phases of the erosion cycle (Figure 2). The classes are further categorized according to whether they apply engineering technology for landforming, placement of materials, or construction of structures and systems. These categories reflect increasing levels of need. Within these categories, the various measures are defined and their purposes and conditions for use are stated.

An overview of erosion processes and their effects is presented. An understanding of these is needed to understand and evaluate alternative erosion control measures. Emphasis is placed on processes which disrupt (and prevent) the physical land degradation process rather than on those which provide superficial treatment of degradation features.

To complete the objectives of the larger research effort, this report will be followed by publications on land evaluation principles for identifying and assessing needs and for selecting cost-effective erosion control technologies.

Mode of Technology Transfer

The information in this report will be incorporated into an Engineering Technical Note or Department of the Army Pamphlet.

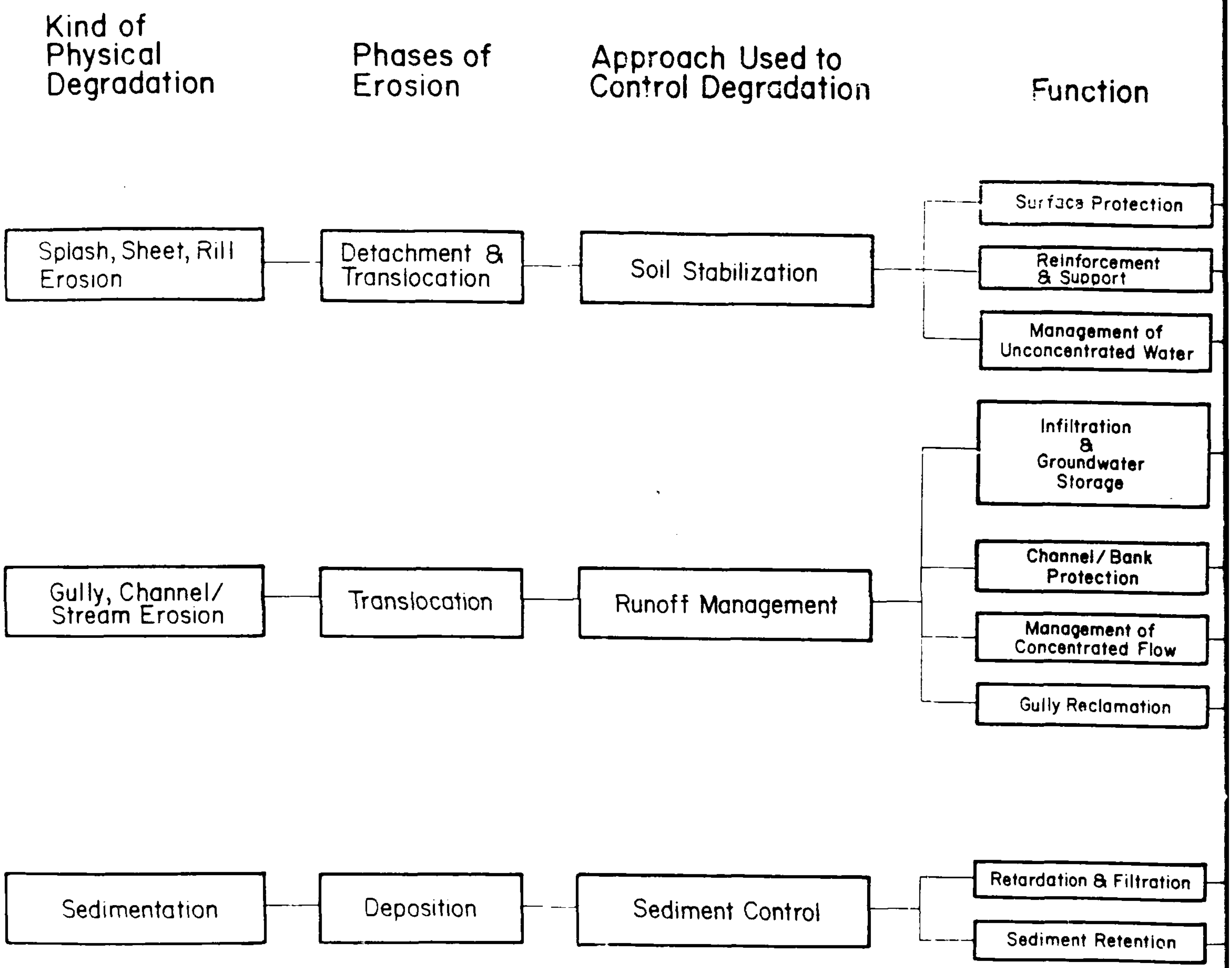
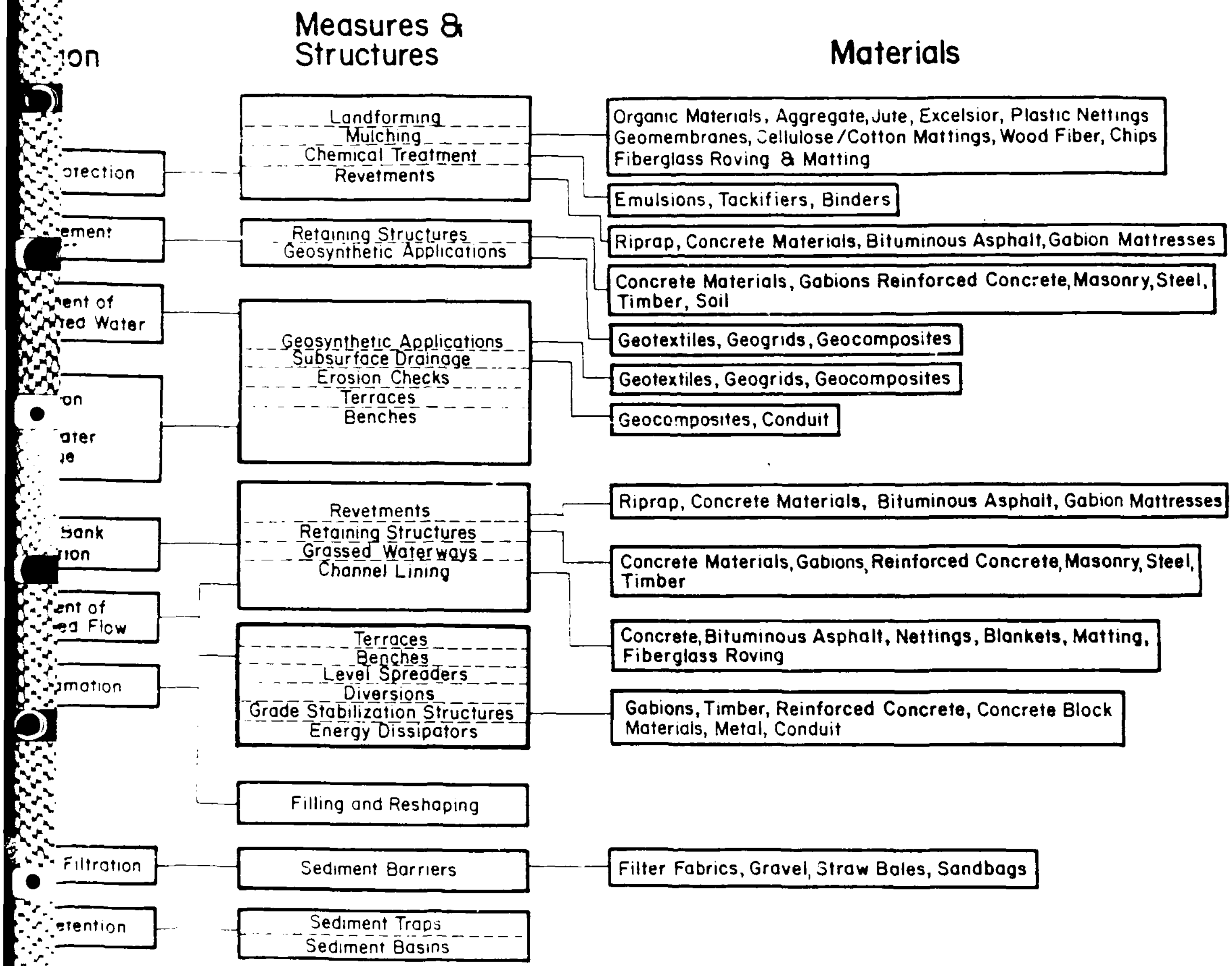


Figure 2. Classification of methods, materials, structures, and systems for soil stabilization, management of runoff, and sediment control. (Adapted from concept in Figure 4-1, Planning Matrix, in *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois* [Northeastern Illinois Soil Erosion and Sedimentation Control Steering Committee, James K. Michels, chairman, 1981].)



Measures & Structures
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Geosynthetic Applications
Subsurface Drainage
Erosion Checks
Terraces
Benches
Revetments
Retaining Structures
Grassed Waterways
Channel Lining
Terraces
Benches
Level Spreaders
Diversions
Grade Stabilization Structures
Energy Dissipators
Filling and Reshaping
Sediment Barriers
Sediment Traps
Sediment Basins
Organic Materials, Aggregate, Jute, Excelsior, Plastic Nettings Geomembranes, Cellulose/Cotton Mattings, Wood Fiber, Chips Fiberglass Roving & Matting
Emulsions, Tackifiers, Binders
Riprap, Concrete Materials, Bituminous Asphalt, Gabion Mattresses
Concrete Materials, Gabions Reinforced Concrete, Masonry, Steel, Timber, Soil
Geotextiles, Geogrids, Geocomposites
Geotextiles, Geogrids, Geocomposites
Geocomposites, Conduit
Riprap, Concrete Materials, Bituminous Asphalt, Gabion Mattresses
Concrete Materials, Gabions, Reinforced Concrete, Masonry, Steel, Timber
Concrete, Bituminous Asphalt, Nettings, Blankets, Matting, Fiberglass Roving
Gabions, Timber, Reinforced Concrete, Concrete Block Materials, Metal, Conduit
Filter Fabrics, Gravel, Straw Bales, Sandbags

2 EROSION PROCESSES

Phases of Erosion

Running water, precipitation, wind, ice, organisms, and humans cause the land-altering effects commonly called erosion. In the erosion cycle, soil or rock particles go through three phases: they are (1) detached, (2) moved (translocated), and (3) deposited (Figure 3). "Erosion processes" include all the ways in which soil or rock material is loosened and removed.

Particles are loosened and detached by processes such as freezing, thawing, raindrop impact, and soil disturbance caused by man and animals. These processes also and alter soil properties which resist the forces of erosion, causing erosion to occur more rapidly.

Soil particles are transported by wind, raindrop splashes, and flowing water. Like wind, runoff can transport sediment over great distances. Runoff can mean surface water flowing either overland or in channels. Overland flow is the gravity-induced flow of a layer of water over the surface of sloping ground. It can take the form of sheet flow (a continuous, thin film), or a series of rivulets (small concentrated flows) connecting one

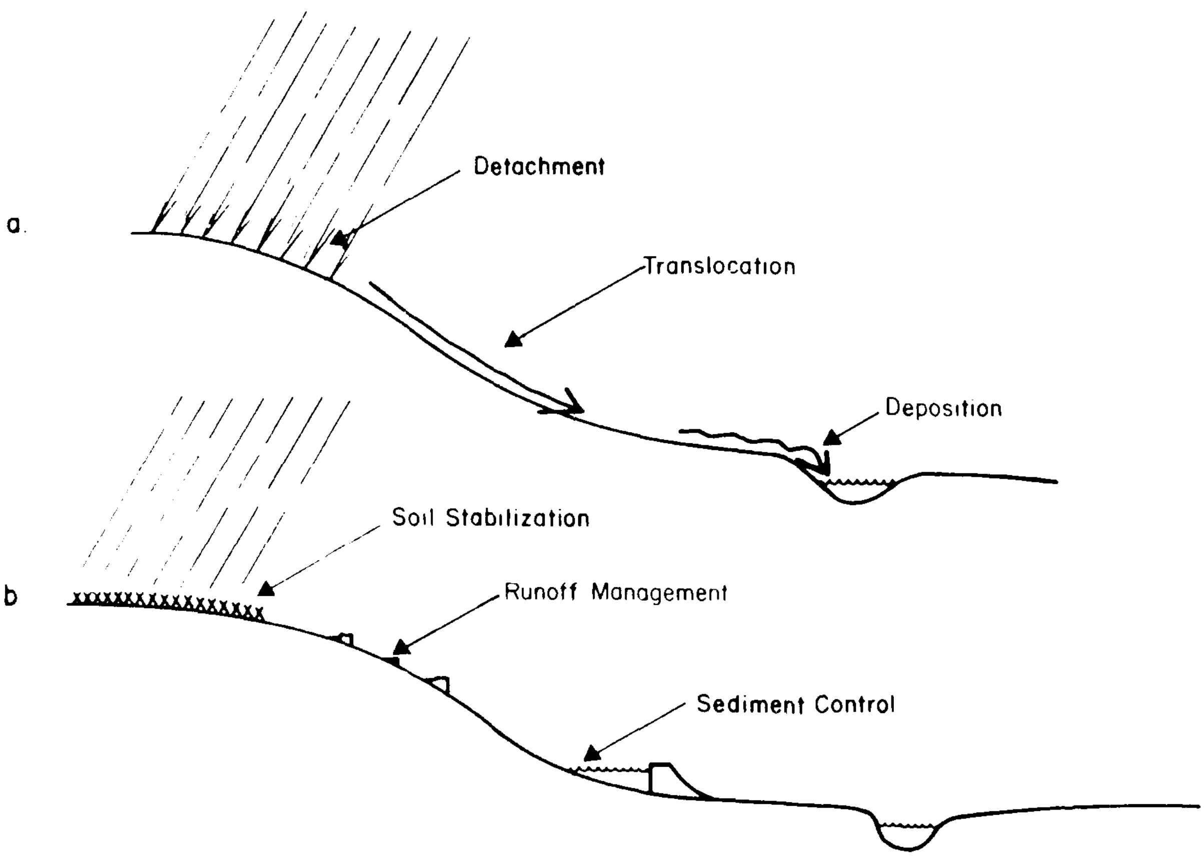

Figure 3. Simplified profile of watershed slope showing (a) continuum of erosion phases, and (b) corresponding control approach.

water-filled depression with another.[1] In channel flow, the water occupies a well-defined channel confined by banks.

All eroded soil eventually enters a stream channel, where it becomes harmful in several ways. It reduces the flow capacity of the stream and causes channel alteration. Increased sediment deposition in stream channels or other water bodies such as lakes and reservoirs may endanger fresh water supplies and seriously damage aquatic life by suffocating it and destroying its habitat.

Effects of Water Erosion

The types of water erosion are defined below in terms of their effects. The various kinds of erosion may occur individually, in combination, or as progressive stages (Figure 4). Not every slope in a given watershed will exhibit these effects uniformly in time or space, because every slope has unique characteristics which determine its erosion potential. Soil characteristics have particular influence upon splash, sheet, and rill erosion, while climate, topography, and surface cover are particularly important factors of gully and channel erosion.

Splash erosion results from the direct impact of falling drops of rain on soil particles where vegetative cover or residue is absent. Besides detaching the soil upon impact, its beating destroys soil structure and aggregation. Fine particles and organic matter are separated out from heavier materials and splashed from their original location into a position where they can be easily transported from the site by surface runoff. In this way, splashing greatly assists and enhances translocation by runoff on a slope or in windy conditions. If the dispersed particles remain in place, they may form a hard crust upon drying, inhibiting the infiltration of water and preventing the emergence of seedlings.

Sheet erosion is the removal of a layer of exposed soil by shallow sheets of water moving over the land surface. It occurs on all land surfaces but is particularly active on gentle slopes where runoff is not concentrated into well-defined rivulets. Since flow is usually laminar, seldom exceeding a velocity of 2 or 3 ft/s,* sediments derived from sheet erosion are fine grained.

Rill erosion occurs as a result of the concentration of overland flow into rivulets that cut into the soil surface. The cutting action is accomplished by a concentrated flow energy which detaches and transports particles. When rivulets create grooves of only a few inches in depth, rills are formed.

Gully erosion may develop where old rills continue to enlarge or where several rills join to form a larger channel. The concentration of water causes scouring of the bottom and sides and sloughing of the sides. In more advanced stages of this process, large portions of soil may fall from unstable areas of the gully walls or adjacent slopes to produce mass wasting.

Streambank and channel erosion occur when runoff volume and velocity increase or when bank vegetation is disturbed. A stream adjusts its gradient and responds to changes

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[1] A. N. Strahler and A. H. Strahler, *Modern Physical Geography*, 2nd ed. (John Wiley and Sons, New York, 1983).

*1 ft = 0.30 m; 1 in. = 25 mm.

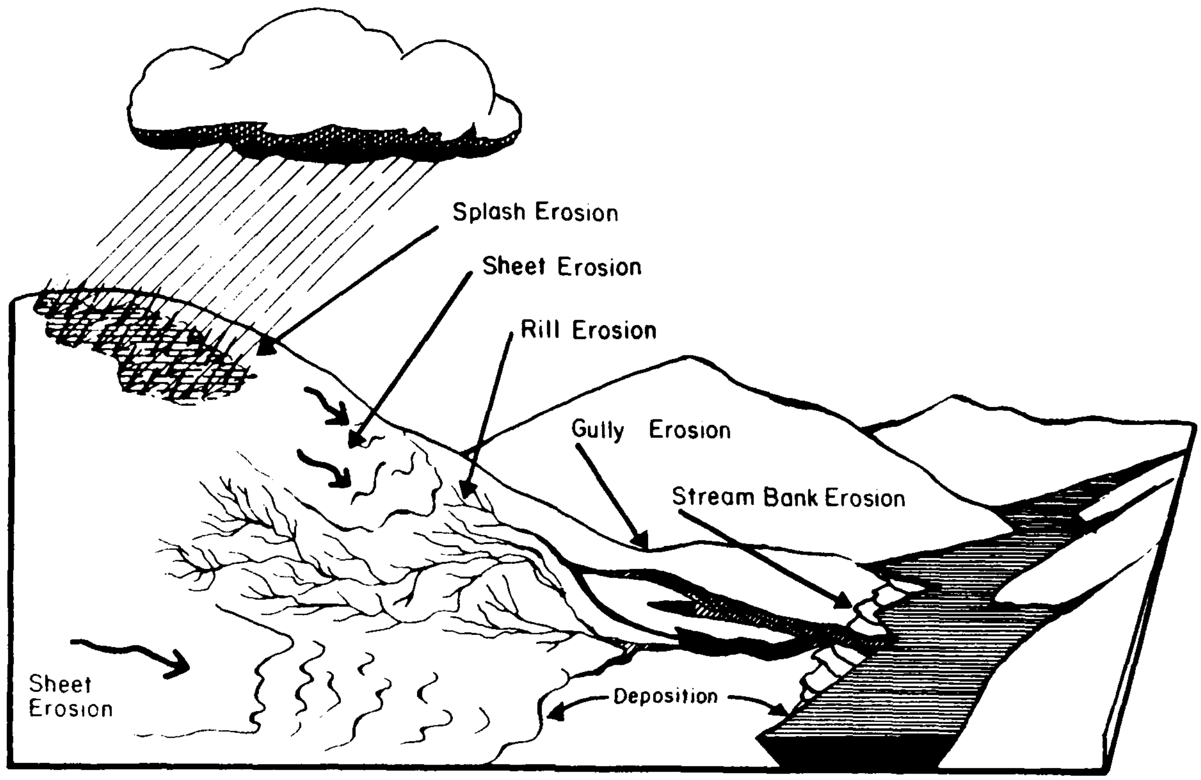

Figure 4. Types of erosion (note that types are not limited to slope position shown, but can occur in a continuum or in combination).

in the erosion rates of slopes through velocity and meander pattern variation, channel erosion, and sediment deposition. When vegetation is removed or the overland flow rates change in the drainage basin, stream velocity and storm peak flows increase as well, causing channel erosion. Downcutting of the streambed also occurs to the limits allowed by the substrate materials.

Accelerated Erosion

Erosion processes are self-perpetuating because they involve a positive feedback mechanism. That is, the results of an erosion process enhance the efficiency of that process, producing greater effects which are followed by even more efficient processes. In this way it is possible for major alterations of landforms to occur in a short time.

Accelerated erosion exists when soil loss exceeds rates considered normal for a particular site. This occurs when degradation processes increase or when conditions are such that resistance to erosion forces diminishes, causing the soil to become especially vulnerable to degradation. Conditions may concentrate runoff into a flow across the site, causing detachment and entrainment of soil particles. Changes in land use or condition affect erosion rates for a given area because the ratio between the effects of erosion and the resistance factors has been changed.

3 PROCESS DISRUPTION

Phase Intervention

Just as certain influences may set up conditions at a site that cause accelerated erosion, measures may be taken to counteract erosion processes. Measures for erosion control can disrupt the phases of erosion by providing soil stabilization, runoff management, and sediment control (Figure 3).

Soil stabilization measures provide protection for the soil surface from erosive impacts of rain and runoff. By preventing splash, sheet, and rill erosion, soil stabilization measures interrupt the first phase of the erosion cycle, the detachment of soil particles. Vegetative cover can provide effective soil stabilization, but in many cases, the physical and biological environment surrounding the vegetation needs the extra stability and protection given by land contouring, emplacement of materials, or structural support measures.

Runoff management measures help manage the concentrated flows of water which can lead to gully, stream, and channel erosion. Runoff is particularly affected by slope degree and slope length. Where surface cover is present, it slows down the runoff by increasing the physical resistance and by taking up the water. Where inadequate surface cover exists and where slopes are particularly steep or long, runoff management measures must be taken to divert flow or keep overland flow and channel velocities low.

Sediment control measures provide for the on-site management of sediment to prevent damage to adjacent properties or downstream waterways. While these measures do not stop the detachment of soil particles, they trap sediments being carried away by runoff.

Because erosion processes are related, a measure for controlling a particular problem associated with one phase will also affect the processes associated with the other phases. Careful consideration must be exercised to insure that these secondary impacts are beneficial rather than detrimental. When properly executed, erosion control measures usually provide multiple land management benefits by disrupting more than one phase of erosion processes. For example, measures which are selected primarily for runoff management will provide soil stabilization as well.

Effects of Vegetation

A variety of engineering technologies for erosion control will be discussed in detail in the remainder of this report, but it is important not to overlook the usefulness of vegetation as a control measure. The establishment of vegetative cover is a relatively inexpensive soil stabilization and runoff management measure that is ideal for most circumstances. By intercepting raindrops, vegetation absorbs rainfall energy, reducing the occurrence of soil particle detachment caused by raindrop impact and splash. Plant residues slow runoff velocities by providing surface roughness. Clumps of vegetation produce a buttressing and soil arching effect. Root systems stabilize the soil by binding soil particles and restraining their movement. Roots and vegetative structures provide mechanical reinforcement because the tensile strength of the roots transfers shear stress away from the soil. Residues and roots also increase soil porosity and permeability, which increases infiltration. A vegetative surface cover also minimizes frost effects by stabilizing soil temperature variability.

Vegetative cover requires an adequate physical and biological environment which provides nutrients, moisture, and physical support to sustain its growth. Erosion processes, however, leave the remaining subsoil hard, rocky, infertile, droughty, and unstable. When vegetative cover is damaged or removed from the land surface, the soil becomes extremely vulnerable to the compounding effects of erosion. These effects and subsequent erosion processes make conditions increasingly more difficult for vegetation to become reestablished. Runoff physically carries away seeds, exposes roots of established plants, and removes from the soil its finer constituents and organic materials containing nutrients. On slopes where the land surface has become unstable, large portions of soil carrying vegetation may be moved out of place, damaging roots and exposing bare subsoil.

Seeding grasses and legumes is the most common and economical method of cover establishment for large areas. Sodding provides immediate turf cover and is recommended where establishment by seeding is difficult. Cuttings of easy-to-root shrub species are commonly used for slope treatment. Contour wattling can be used to reduce a long slope to a series of short slopes by placing bundles of easy-to-root, woody plant species in trenches, then staking and shallowly covering them.[2] While vegetation is being established, the slope is stabilized by the bundles and stakes, runoff is reduced, and sediments are trapped. Where available and convenient, stakes made from the live wood of easy-to-sprout species can be driven through the bundles, providing mechanical stability as well as additional vegetation after they sprout roots.[3] Planting or driving unrooted cuttings is known as sprigging. Brush layering, which is also used to stabilize slopes using branches of suitable shrubs, involves inserting the branches into trenches or benches perpendicular rather than parallel to the slope.

Engineering Applications for Erosion Control

Sound land use practices and proper vegetative applications are necessary in a good soil and land management system. In some cases, however, vegetative applications and routine maintenance measures may not be adequate to handle the problems posed by a combination of particular soil conditions, topographic features, and concentrated flows of water. This is especially the case on Army training lands where intensive land use by tactical vehicles may endanger the vegetative cover, creating conditions that could accelerate erosion. In addition, factors such as climate, disease, and pestilence make success of vegetative control measures uncertain or unreliable. Such problems can be solved using engineering technology for land contouring, placement of materials, and construction of structures in conjunction with vegetation and proper land use practices.

Such engineering measures are described here to familiarize the reader with state-of-the-art erosion control technologies (Figure 2). This information is presented only in general terms, for comparison. It is not intended as technical guidance. The reader should refer to the appropriate U.S. Department of Agriculture (USDA) Engineering Field Manuals and other information sources for technical specifications and guidance for implementing specific erosion control measures and revegetation practices (see references).

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[2] D. H. Gray and A. T. Leiser, *Biotechnical Slope Protection and Erosion Control* (Van Nostrand Reinhold Co., New York, 1982).

[3] D. H. Gray and A. T. Leiser.

4 SOIL STABILIZATION

Landforming Measures for Soil Stabilization

Landforming mechanically reshapes the land surface. Slope erodibility increases as slope length and the quantity of water collected by it increase.[4] Landforming measures such as diversions, terraces, and benches provide both soil stabilization and runoff management by shortening slopes and collecting runoff for safe disposal. These measures are discussed in detail in Chapter 5 under **Landforming Measures for Runoff Management.**

Slope stability is sometimes improved by using shaping and grading to reduce the slope or by removing earth to control the loading. Land reclamation practices that prevent or stabilize landslides may also prevent excessive erosion and sedimentation. Measures developed to provide slope stability should always be based on stability analyses made by a qualified engineer trained in soil mechanics with expertise in soil engineering.

Materials for Soil Stabilization

Raw materials and manufactured products can stabilize the soil when they are applied to the soil surface or embedded below it. The type of material used depends on the desired effects, site conditions, availability, and economics. In some cases, the purpose is to provide an erosion-resistant, compacted surface suitable for vehicular traffic.[5] Other purposes may include preventing surface compaction, conserving moisture, minimizing splash and sheet erosion, and helping establish plant cover. Many of the materials described in this section are also suitable for use as runoff management measures (see Chapter 5). Natural raw materials may be organic or inorganic; manufactured products may be natural or synthetic materials.

Mulches

Definition. Mulches are suitable natural or manufactured materials that are applied to the soil surface.

Purpose. Mulching conserves moisture, prevents surface compaction and crusting, reduces runoff, controls weeds, and helps to establish plant cover.[6] Mulching interrupts erosion processes by dissipating the impact of raindrops and minimizing splash erosion and surface sealing. It retards runoff, traps sediment, and creates a microclimate which promotes germination and early development of plants.[7] Aeration of clayey soils is increased as mulch gradually becomes mixed with the soil. In addition to their soil

[4] *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series (U.S. Environmental Protection Agency [USEPA], Office of Research and Monitoring, Washington, DC, 1972).

[5] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois* (Northeastern Illinois Soil Erosion and Sedimentation Control Steering Committee, James K. Michels, chairman, 1981).

[6] *Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas*, National Technical Information Service Report No. PB281278 (U.S. Soil Conservation Service, College Park, MD, 1975).

[7] D. H. Bache and I. A. MacAskill, *Vegetation in Civil and Landscape Engineering* (Granada Technical Books, London, 1984).

stabilization advantages, mulches retain moisture, control surface temperature fluctuations of the soil, and protect against burnout by the sun. Proper installation methods and effective fastening techniques must be followed for them to be successful.

Conditions for Use. Mulches are used on disturbed areas where erosion and climate make it difficult to establish vegetation. The choice and amount of mulching materials depends upon the following factors:

- Desired effect
- Availability
- Cost
- Site characteristics

  Surface roughness
  Aspect
  Slope degree and length
  Soil structure
  Soil texture
  Soil erodibility

- Precipitation characteristics

  Rainfall/snowfall amounts
  Intensity and seasonal distribution of storms

- Materials characteristics

  Weight
  Density
  Roughness
  Durability
  Tenacity
  Application requirements
  Chemical characteristics
  Decomposibility

Organic Mulches. Organic mulches include plant residues (such as straw, hay, leaves, cornstalks, corncobs), and wood residues (such as sawdust, shredded bark, and woodchips) that are applied to the soil surface. Organic mulches are often residues from agricultural crops or industrial raw material waste.[8] The most cost-effective use of natural, raw, organic materials generally results from using appropriate materials available from locally grown crops and nearby industry.

Straw and hay usually must be held in place to prevent the wind from blowing them away. Specially designed machinery is used for crimping, disking, rolling, or punching to accomplish this task. Other methods include covering the straw/hay with netting or spraying it with a chemical to make it tacky.

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[8] B. L. Kay, "Mulches for Erosion Control and Plant Establishment on Disturbed Sites," *Proceedings: High Altitude Revegetation Workshop No. 3*, S. T. Kenny, ed.; Colorado Water Resources Research Institute Series, No. 28 (Colorado State University, Fort Collins, CO, 1978).

While mulching can be beneficial, there are some problems associated with mulching materials. Organic mulches with a very high carbon to nitrogen ratio, such as straw and wood waste materials, often require additional nitrogen to compensate for the immobilization of inorganic nitrogen during the decomposition process.[9] Mulches may create a toxic condition for germinating seedlings if they are high in nitrogen (producing a high ammonium concentration), or if they contain phytotoxic materials.[10] In some cases, germination and plant growth may be slowed due to lower temperatures or water immobilization. Also, mulches may become a fire hazard or harbor unwanted insects, fungi, diseases, and rodents which destroy the seeds or seedlings[11]

Naturally Occurring Aggregates. Aggregate covers provide immediate stabilization and erosion protection for sites where vegetation cannot be readily established. Shallow layers of pebbles, gravel, crushed stone or lava chips can be used as inorganic mulches for short, low to moderately steep slopes.[12] Lightweight materials such as expanded shale or seashells may be used where loading becomes an important factor for slope stability.

Aggregate cover also provides stabilization and erosion protection by establishing a compact, erosion resistant surface suitable for vehicular traffic. Seashells have been used in 5- to 7-ft layers to form a supportive foundation for traffic over surface swamp deposits.[13] This lightweight fill reduces the foundation stresses which may be caused by the fill. Aggregate composition and costs reflect the availability of geologic resources.

Manufactured Products for Mulching. Manufactured products used for soil stabilization include a variety of natural and synthetic materials such as netting, meshes, fabrics, geosynthetics, fiberglass products, and chemical emulsions. Some of these products are used as mulches to hold soil in place and absorb and retain moisture, while others act as reinforcements, separators, or filters between soils, sediments, groundwater, and construction materials. Because these products are generally produced in rolls, their major drawback is the difficulty of proper installation, especially in rocky areas and over rough surfaces.[14] This presents the risk of erosion occurring beneath the products due to a lack of complete, firm contact with the soil. Labor costs for installing these materials may also considerably exceed those for tacked straw.

Dense, fibrous, woven materials such as jute, excelsior, and cellulose/cotton can be used as mulching blankets. They are primarily used for temporary protection in critical areas where vegetation is being established. The use of erosion checks for runoff management is strongly recommended in conjunction with these types of mulching blankets.[15] Erosion checks are discussed in the section entitled **Structures and Systems for Soil Stabilization.**

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[9] *User Guide to Vegetation Mining and Reclamation in the West*, U.S. Department of Agriculture (USDA) Forest Service General Technical Report INT-64 (Intermountain Forest and Range Experiment Station, Forest Service, USDA, Ogden, Utah, 1979).
[10] *User Guide to Vegetation Mining and Reclamation in the West.*
[11] *User Guide to Vegetation Mining and Reclamation in the West.*
[12] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*
[13] D. S. Gedney and W. G. Weber, Jr., "Design and Construction of Soil Slopes," *Landslides: Analysis and Control*, R. L. Shuster and R. J. Krizek, eds.; National Academy of Sciences Special Report 176 (Transportation Research Board, 1978), pp 172-192.
[14] B. L. Kay.
[15] *Guidelines for Erosion and Sediment Control Planning and Implementation.*

Jute netting consists of thick strands of jute fibers woven into a heavy mesh (Figures 5 and 6). It can be treated for smolder resistance. Complete contact with the soil is necessary to ensure that water does not flow beneath the jute. The top ends of the jute strips are buried securely in slit trenches in the soil to check water flow and improve tie-down.[16] Wire staples or wooden pegs may be used to secure the jute. See the section entitled **Materials for Runoff Management** for uses of jute netting in managing concentrated flow.

Excelsior blankets are manufactured mats consisting of curled wood excelsior fibers several inches in length. Blankets usually are smolder resistant and have a backing of woven, twisted Kraft paper or biodegradable plastic mesh. They should be positioned weave side up with ends butted and securely stapled to the soil.[17] Excelsior blankets, like other nettings and mattings, must be in complete contact with the soil to ensure that water does not flow beneath, causing erosion. See the section entitled **Materials for Runoff Management** for uses of excelsior blankets in managing concentrated flow.

Cellulose/cotton mattings are especially useful on small, critical areas as mulching materials.[18] They are manufactured from cellulose and cotton or as a composite of various fibers that are bonded with a water soluble binder Some products also have plastic netting and may include seed and fertilizer within the fibrous blanket. When saturated with water, the matting loosens to form a thick mulch cover which holds the underlying seed and soil in place. It must be secured firmly to the soil to prevent uplift or damage by wind and to keep runoff from flowing beneath the matting. Although these products are weed-free, they may present a fire hazard and may, in some cases, be too biodegradable to be effective.[19] See the section entitled **Materials for Runoff Management** for uses in managing concentrated flow.

Wood fiber mulch is a short fiber product made from wood chips. A fugitive, nontoxic, green dye is generally used to color it to aid in application procedures. It is specifically designed for use as a hydraulic mulch (hydromulch) to promote the establishment of a vegetative cover. The fibers form an absorbent cover, allowing water to filter into the underlying soil while dissipating falling raindrop energy and insulating the seeds and seedlings from solar radiation. The fiber is mixed with water in a slurry tank with appropriate quantities of seed, fertilizer, and other desired additives. After agitation, the well-mixed slurry is mechanically sprayed onto the site. Particles must be small enough to allow easy pumping, yet not so buoyant that they remain in suspension with agitation.[20] It is very important that the hydromulching material adhere to soil on slopes. Although virgin wood fibers adhere well to slopes, glues or tackifiers are sometimes added to improve their resistance to the effects of wind and heavy rainfall on steep slopes. A disadvantage of performing hydromulching and hydroseeding in a single operation is that seeds may not have adequate soil contact. A single operation also requires enough moisture to keep the seeds moist for two to three weeks after seeding.[21]

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[16] *Guidelines for Erosion and Sediment Control Planning and Implementation.*
[17] *Guidelines for Erosion and Sediment Control Planning and Implementation.*
[18] B. L. Kay.
[19] B. L. Kay.
[20] B. L. Kay.
[21] *User Guide to Vegetation Mining and Reclamation in the West.*

Figure 5. Installation of rolls of jute netting. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [U.S. Environmental Protection Agency [USEPA], Office of Research and Monitoring, Washington, DC, 1972], p 174.)

Figure 6. Thick strands and heavy mesh construction of jute netting. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 174.)

Fiberglass matting is a flexible fiberglass produced in roll form. It consists of inorganic material that will not rot or burn. Fiberglass matting is used in erosion check construction to provide resistance to surface erosion and to serve as a mulch for vegetation. It provides soil stability when used as a filter/separator between topsoil and gravel drainage beds.

Another fiberglass product, stranded fiber glass roving, can be used for mulching. This material can be dispensed by means of an air compressor unit which separates glass fiber strands, spreading them evenly over the soil in the form of a strong web (Figure 7). Strands of this nonbiodegradable product become attached to surface irregularities, reinforcing the turf and eventually becoming an integral part of it.[22] See section entitled "Materials for Runoff Management," for application in controlling concentrated flow.

Chemical tackifiers are liquid chemical products which act as soil stabilizers by bonding mulches, seed, and fertilizer on the soil surface like a blanket. They reduce mulch loss due to wind and rain. These products may be similar to soil binder emulsions, or they may consist of emulsions of high strength rubber or liquid asphalt in which the basic component is asphalt cement.[23] Dispersing equipment such as sprayers and hydroseeding equipment is used to apply tackifiers. Curing conditions, time requirements, and handling limitations vary greatly. Plant species must be considered when choosing a product since some species react negatively to these products.[24]

Geosynthetic Materials

Definition. Geosynthetics are synthetic products used for geotechnical purposes below or on the soil. Geosynthetics are separated into four major subgroups called geotextiles, geomembranes, geogrids, and geocomposites.

Purpose. Geosynthetic materials provide soil stabilization and reinforcement.

Conditions for Use. Geosynthetics are used where conventional methods may be restrictive, more costly, unreliable, or unpredictable.

Geotextiles. These are synthetic fabrics that are permeable to fluid flow with cross-place permeability comparable to medium sand to fine gravel.[25] They may be woven or unwoven fabrics with fibers manufactured from polymers such as polyethylene, polyester, polypropylene, or polyamide. Woven fabrics are comprised of filaments (monofilament, multifilament, or a ribbon of slit-film) or yarns overlapped in perpendicular directions. Nonwoven fabrics may consist of a mat of discrete fibers that may be entangled or bonded by needle punching, spunbonding, or resin bonding.[26]

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[22] *Guidelines for Erosion and Sediment Control Planning and Implementation.*
[23] *Guidelines for Erosion and Sediment Control Planning and Implementation.*
[24] *User Guide to Vegetation Mining and Reclamation in the West.*
[25] W. Deutsch, "Geosynthetics: A Brief Overview," *The Weston Way*, Winter/Spring 1986 (Roy F. Weston, Inc., West Chester, PA, 1986).
[26] Q. L. Robnett and J. S. Lai, "Use of Geotextiles to Extend Aggregate Resources," in *Extending Aggregate Resources*, American Society of Testing and Materials (ASTM) Special Technical Publication 774 (ASTM, Baltimore, MD, 1980), pp 178-195.

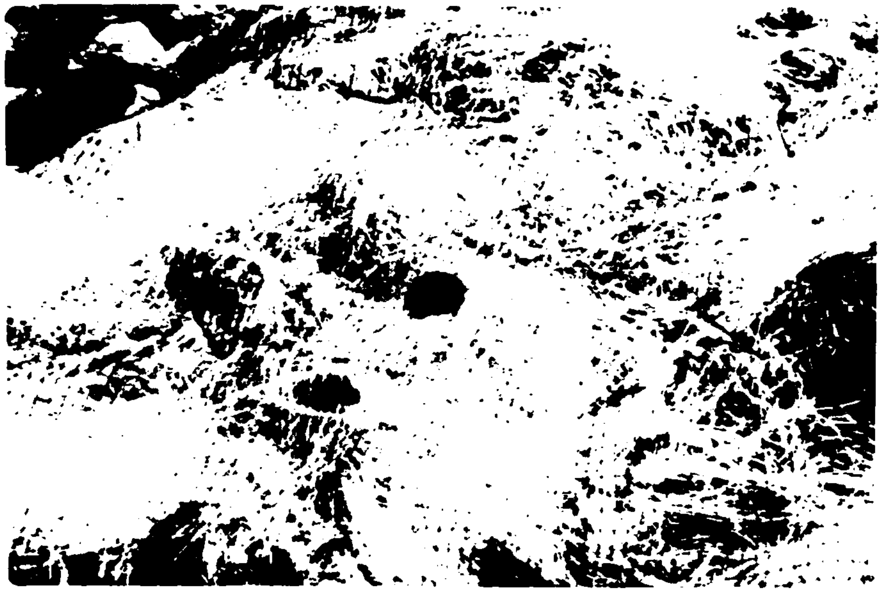

Figure 7. Plastic netting used over fiberglass roving. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [U.S. Environmental Protection Agency, Office of Research and Monitoring, Washington, DC, 1972], p 180.)

The important mechanical properties to consider choosing include

- Tensile strength
- Grab modulus
- Friction/adhesion
- Creep
- Bond strength
- Fatigue
- Failure elongation
- Burst strength
- Temperature and ultraviolet stability
- Chemical and biological stability
- Coefficient of permeability
- Lateral hydraulic transmissivity.

Geotextiles act as filters, separators, and reinforcers. As filters, geotextiles prevent fine sediments from clogging drainage systems and causing sedimentation problems. Geotextiles are also used as filter fabrics and blankets to prevent undermining of riprap or other materials used for channel lining. As separators, they prevent fine grained sediments from mixing with aggregate and other construction materials,

preserving the design load-bearing capacity. They reinforce weak load-bearing soils by promoting drainage and reduce localized loads by being placed into tension as a support layer. These products provide alternate ways of extending conventional construction resources and may result in superior benefits.

Geomembranes. These are impervious sheets of synthetic materials commonly used for flexible containment linings. Polyethylene sheeting can protect soil against sheet erosion from surface runoff. Clear plastic is used when seeds are planted; dark-colored sheeting is used when seeding is not being done.[27]

Geogrids and Geocomposites. Geogrids range from rigid to somewhat flexible grid structures whose openings make them unsuitable for separation and filtration. Their high tensile strength makes them ideal for soil reinforcement and stabilization applications. Geogrids provide stabilization for roadways, embankments, slopes, and backfill behind retaining walls. Generally manufactured in roll form, geogrids can be rolled out for use as mattings. The voids of the three-dimensional construction are then filled with soil or other appropriate material. Such matting dissipates rainfall energy, minimizes particle transport, prevents seed disturbance, and acts as a reinforcing matrix for roots of vegetation.

Geocomposites consist of various combinations of geotextiles, geomembranes, geogrids and other products, which may include natural materials. They may combine the functions of filtration, soil separation, and reinforcement to provide stabilization for particular site conditions. Many geocomposites are constructed for subsurface drainage applications. They promote soil stability by dewatering saturated soil and reducing hydrostatic pressure.

Chemical Stabilizers and Soil Binders

Definition. Chemical stabilizers and soil binders are emulsions that are applied to the soil surface to control erosion. Some emulsions used are polyvinyl acetate homopolymers, latex acrylic-balanced copolymers, or vinyl acrylic copolymers, commonly called PVA.[28]

Purpose. Chemical stabilizers and soil binders are used to bind surface soil particles or to form a crust that provides temporary soil stabilization.

Conditions for Use. These products are used where soil surfaces are subject to erosion by wind and water. If seeding is being done as part of the operation, wood fiber should be included in the emulsion treatment to prevent seed and fertilizer from readily washing off soil slopes. Proper drying conditions and curing temperatures are required for these emulsion products.

While plastic emulsions generally are not toxic to plants, they commonly reduce establishment, retard the emergence of grass seedlings, and produce tip burn (particularly in sandy soils). Some of these problems may be due to the effects of the fertilizer rather than the emulsion itself. Fertilization can be delayed until after seed germination to avoid fertilizer burn.[29]

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[27] B. L. Kay.
[28] B. L. Kay.
[29] B. L. Kay.

Concrete Block Materials

Definition. Blocks are manufactured in a variety of shapes and sizes including standard rectangular building blocks having cellular voids, trough-shaped cement blocks which hold soil materials and moisture, and concrete waffled slabs of varying dimensions.

Purpose. Concrete block materials provide soil stabilization as structural components on slopes and on level areas through load distribution.

Conditions for Use. Concrete blocks provide soil stabilization when used on slopes and as components for revetments and retaining walls. Some concrete grids having flat surfaced interlocking designs are suitable for applications on level, unpaved areas requiring protection from traffic. These materials provide soil stabilization through load distribution.

Structures and Systems for Soil Stabilization

Structures for soil stabilization protect slopes and graded areas by protecting the surface from the particle detaching effects of sheet and rill erosion, by preventing undercutting of a slope at the base, and by managing excess surface water. They can be built from both artificial and natural materials. Natural materials, which are usually less costly when locally available, include earth, rock, stone, and timber. Artificial materials, generally more costly but more durable as well, include cement, bituminous asphalt, steel. and geosynthetics.

Erosion Checks

Definition. Erosion checks are structures of nonerodible, porous materials placed in a trench situated perpendicular to the flow of water (Figure 8).

Purpose. Erosion checks prevent sheetwash on slopes and channel erosion in swales and channels. They prevent removal of soil particles and the formation of rills and gullies by allowing subsurface water to migrate through porous materials.

Conditions for Use. Erosion checks are used in swales and drainageways where vegetation is being established. They provide grade control on slopes where severe sheetflow problems occur.[30] They are commonly used in conjunction with mulching blankets.

Revetments

Definition. Revetments are protective facings of banks, embankments, or slopes. They may consist of materials such as rock, concrete facings, bituminous asphalt pavement, grids, sacked concrete, blocks, mortared riprap, or gabion mattresses (Figures 9 and 10).

Purpose. Revetments provide structural, erosion-resistant armoring for embankments. They prevent raindrop and sheet erosion on slopes and prevent scour by running water at their bases.

[30] *Guidelines for Erosion and Sediment Control Planning and Implementation.*

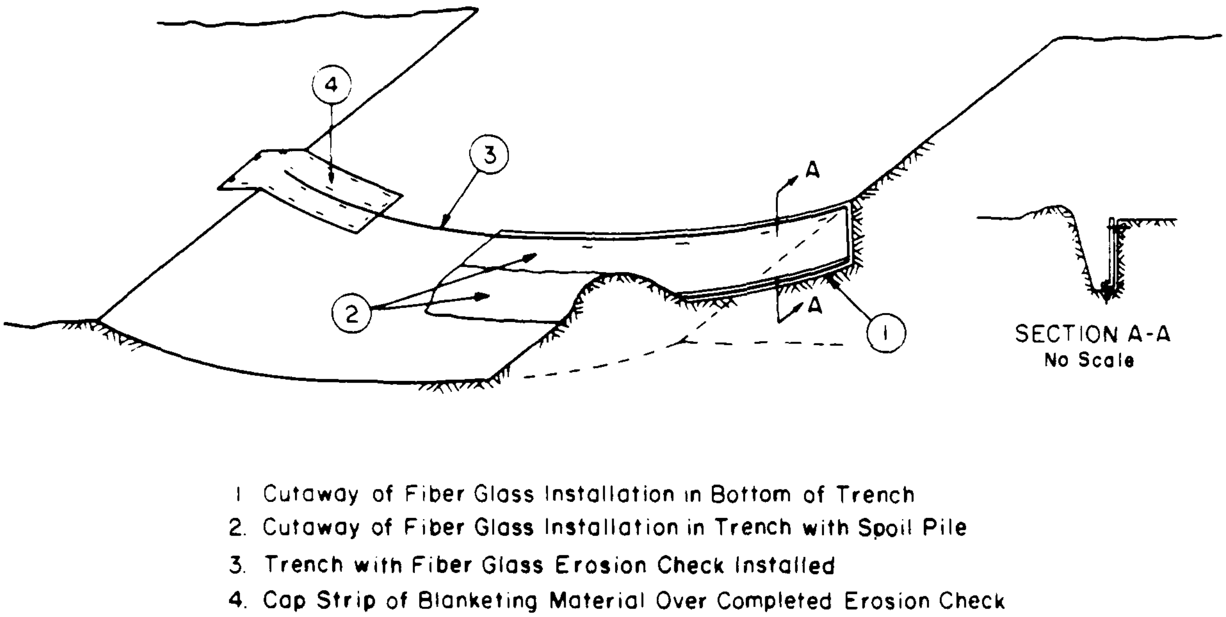

Figure 8. **Erosion check construction.** (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 111.)

Figure 9. **Rock slope protection.** (Source: *Bank and Shore Protection in California Highway Practice* [State of California Business and Transportation Agency, Department of Public Works, Division of Highways, Sacramento, CA, 1970], p 93.)

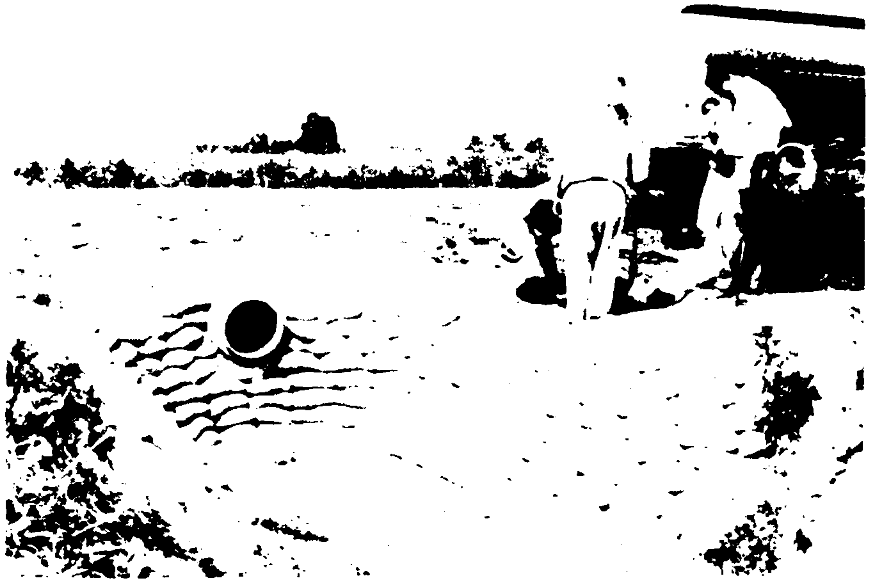

Figure 10. **Sacked concrete revetment.** (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 30.)

Flexible Revetments. These structures can adjust to minor settlement and changes in foundation conditions. Riprap and some gabion structures are flexible. These structures act as protective barriers against erosive energy that would otherwise be directed at erodible soils. Technical Manual (TM) 5-820-4 provides guidelines for using riprap protection.[31] Riprap structures are not weakened or impaired by slight settlement of the embankment.[32] Vegetation often grows through the rocks, adding stability and a more natural appearance. In some applications, riprap is grouted with portland cement mortar to fill the spaces.

Rigid Revetments. These structures require a firm, stable foundation and careful design. Materials should extend several feet below the existing ground surface to prevent undercutting at the toe.[33]

Pavements are rigid revetments used in places where vegetation cannot be established or where aggregate cover cannot be maintained. Care must be taken, however, to ensure that paving does not contribute to off-site erosion problems. Proper installation requires that embankments be well-drained to prevent damage from occurring beneath the pavement due to hydrostatic pressure. Subgrades must be

[31] Technical Manual (TM) 5-820-4 (Air Force Manual 88-5, Chapter 4), *Drainage for Areas Other Than Airfields* (Departments of the Army and Air Force, 14 October 1983), p 5-1.

[32] *Bank and Shore Protection in California Highway Practice* (State of California Business and Transportation Agency, Department of Public Works, Division of Highways, Sacramento, CA, 1970), p 93).

[33] *Guidelines for Erosion and Sediment Control Planning and Implementation.*

compacted and stable to prevent cracking or failure. Expansive clays provide unstable support due to their movement which causes buckling of concrete pavement.[34] Soils of low density must be compacted or replaced by suitable material.

Retaining Structures

Definition. Retaining structures are constructed devices placed at the foot of embankments.

Purpose. Retaining structures protect the toe and slope surface against erosion and prevent mass movement of soil.

Conditions for Use. Retaining structures are used in situations where slope stabilization against erosion and mass movement of soil and protection against erosion at the toe is required. These structures are classified into these basic types by Gray and Leiser:[35]

- Gravity walls
- Crib walls
- Reinforced soil walls
- Gabion and welded-wire walls
- Pile walls
- Tie-back walls
- Cantilever and counterfort walls.

Several of these are illustrated in Figure 11.

Gravity Walls. These are constructed from stone, concrete, or masonry. While they resist earth pressure by their weight or mass, they can not resist appreciable tension. A breast wall is a kind of gravity wall that is erected on firm ground against a slope with only a small amount of fill behind it. Constructed with irregularly shaped rock, they are porous, allowing vegetation to fill the voids. Breast walls are not designed to resist large lateral earth pressures.[36]

Crib Walls. These are constructed from timber, concrete or steel beams in an interlocking box shape that is filled with soil and/or rock (Figure 12). The cribbing can be designed with openings to accommodate vegetation. The structure can be tilted back for added stability and has flexibility to withstand some differential settlement. Its design must be internally stable, with the materials being capable of resisting stresses of both the cribfill and the backfill.[37]

Reinforced Soil Walls. These consist of a granular fill reinforced with successive layers of metal strips. The metal strips are connected to facing elements that are stacked on top of each other. Soil walls can also be constructed using a nonwoven, needlepunched geotextile that encapsulates a granular, drainable backfill. Layers of encapsulated fill are stacked and anchored. A protective facing is then applied.

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[34] *Design of Roadside Drainage Channels*, Report No. PB86-180288, Hydraulic Design Series No. 4 (Federal Highway Administration, Washington, DC, 1965).
[35] D. H. Gray and A. T. Leiser.
[36] D. H. Gray and A. T. Leiser.
[37] D. H. Gray and A. T. Leiser.

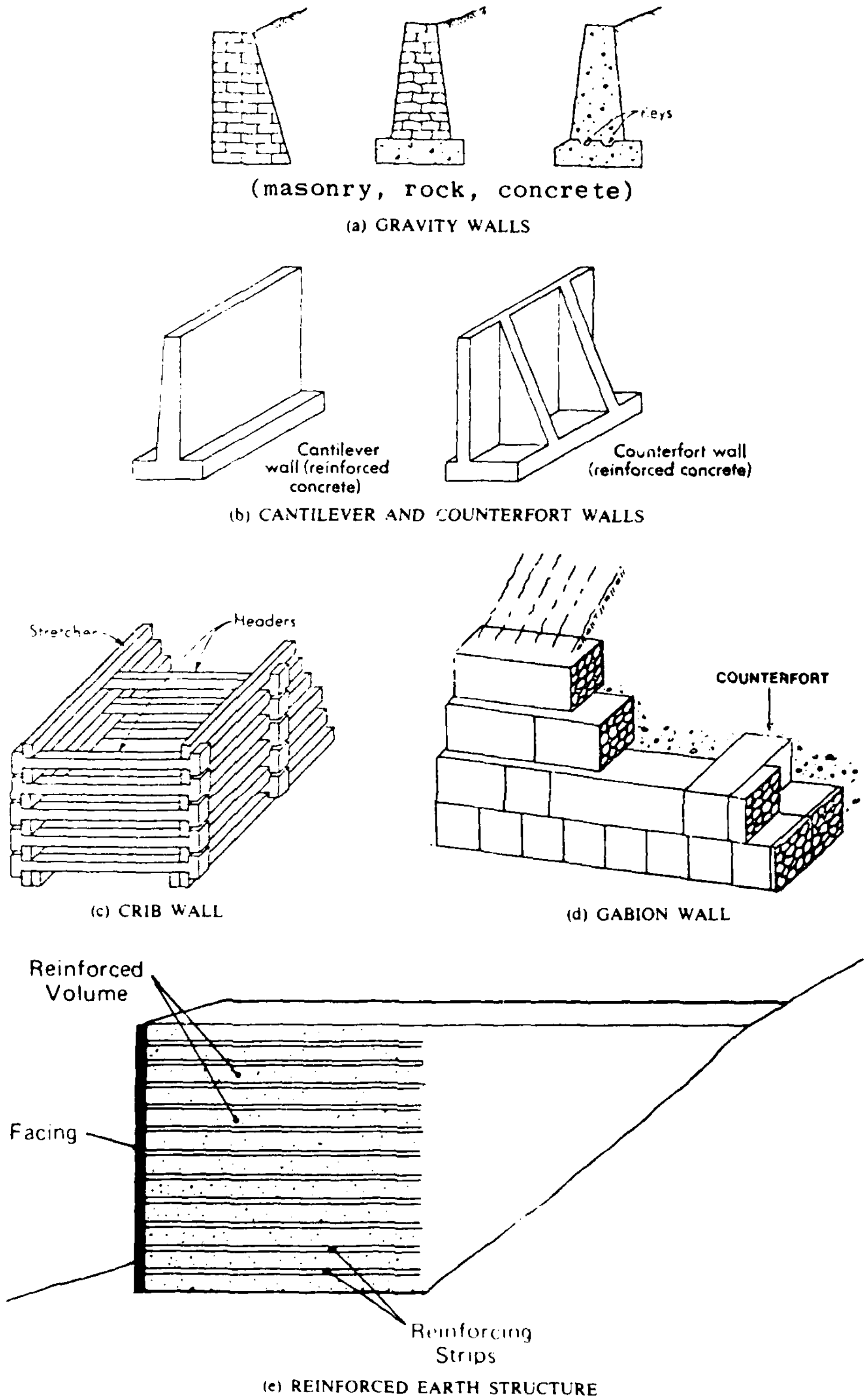
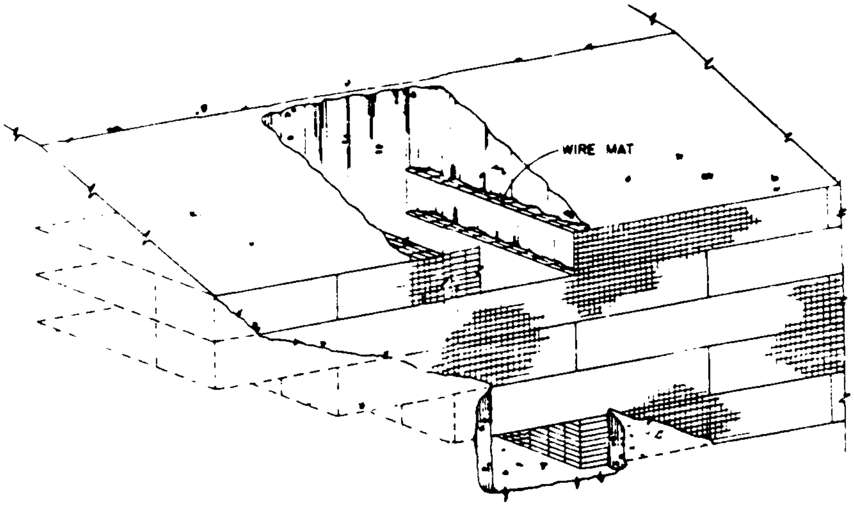
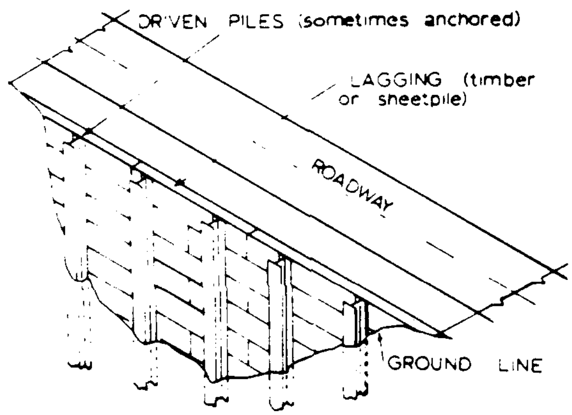


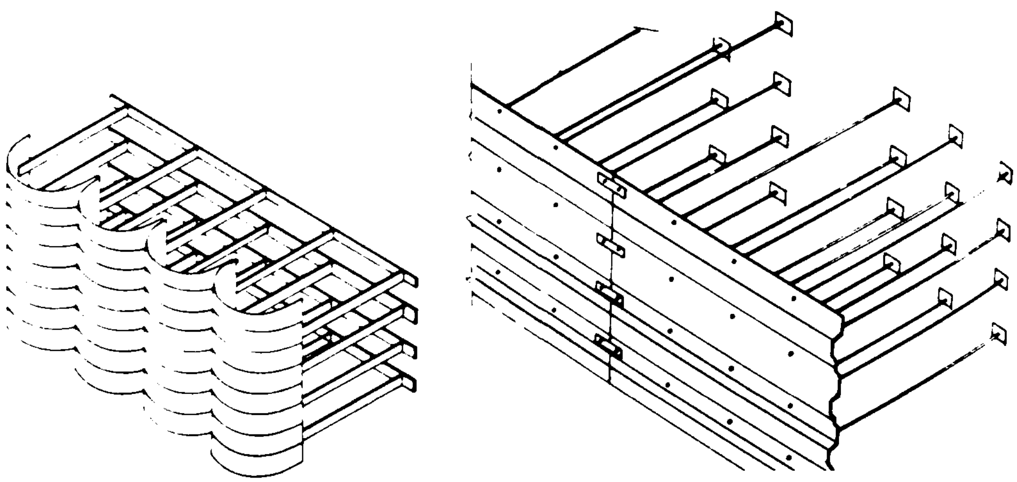
Figure 11. Retaining structures. (Source: D. H. Gray and A. T. Leiser, *Biotechnical Slope Protection and Erosion Control* [Van Nostrand Reinhold Co., New York, 1982], p 86-87. Used with permission.)



(f) WELDED-WIRE WALL



(g)



(h)

Figure 11 (Cont'd).

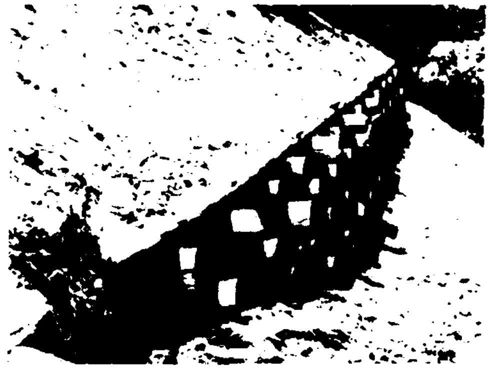


Figure 12. Log crib for slope stabilization. (Source: *Bank and Shore Protection in California Highway Practice* [State of California Business and Transportation Agency, Department of Public Works, Division of Highways; Sacramento, CA 1972], p 99.)

Gabion and Welded-Wire Walls. These are constructed with rock- or stone-filled wire mesh boxes (gabions) that are wired together to form massive but flexible structures that can withstand some settlement (Figure 13). Internal stability is provided by the shear strength of the gabion fill, and resistance to lateral earth forces is derived from its weight. Walls can be constructed with one or more tiers. As more tiers are used, the foundation must be increased and/or counterforts used to brace the wall against overturning. The number and arrangement of gabion units also depends upon whether a level or inclined backfill should be used behind the wall. Walls higher than 9 ft should be designed under the supervision of a registered civil engineer.[38]

Welded-wire walls have features of gabions and reinforced soil walls. L-shaped sections of welded, steel-wire fabric are placed and connected between lifts of compacted, coarse, granular backfill. The mesh contains and reinforces the backfill and allows plants to root, helping to bind the structure into a monolithic mass.

Pile Walls. These consist of bored, cast-in-place, concrete cylinder piles or driven, steel H-piles. They are used where shallow residual soils have beneath them a zone of weathered rock that increases in competency with depth.[39]

Tie-Back Walls. These consist of flexible facing or sheeting held in place by a network of anchored tie rods installed perpendicular to the sheeting. Various kinds of sheeting panels and tie rods are used in their design.[40]

Cantilever and Counterfort Walls. These walls are constructed from reinforced concrete and require careful design to withstand bending and cracking. Cantilever walls, used for heights up to 30 ft, are reinforced vertically and horizontally. Counterfort walls, commonly used for heights greater than 25 ft, have buttresses behind them which are reinforced to resist tension.[41]

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[38] D. H. Gray and A. T. Leiser.
[39] D. H. Gray and A. T. Leiser.
[40] D. H. Gray and A. T. Leiser.
[41] D. H. Gray and A. T. Leiser.

Figure 13. Gabion retaining wall and revetment. (Source: Maccaferri Gabions, Inc., Dallas, TX. Used with permission.)

Subsurface Drainage Systems

Definition. Subsurface drainage is the removal of excess ground water through drains. Drains are any type of buried conduit made from clay, concrete, bituminized fiber, metal, plastic, or other material of suitable quality. They have open joints or perforations which collect and/or convey drainage water.[42] Relief drains are those installed approximately parallel to the flow of groundwater, while interception drains are installed at approximately right angles to the flow of groundwater to intercept flows.[43]

Purpose. Subsurface drainage stabilizes retaining walls, foundations, and embankments. Subsurface drainage systems increase water storage in the soil by removing water slowly. They also reduce surface runoff by lowering the water table and increasing storage volume prior to storms.[44] Besides providing relief drainage by lowering a water table of low gradient, subsurface drainage also provides interception drainage to reduce the flow and lower the flowline of subsurface water (Figure 14).

Conditions for Use. Subsurface drainage is used at wet sites. The proper type of drainage system for a given site is determined by considering the topography of the land

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[42] *USDA Soil Conservation Service National Engineering Handbook*, Section 16, "Drainage of Agricultural Land" (USDA Soil Conservation Service, Washington, DC, 1971).

[43] *Engineering Field Manual* (USDA Soil Conservation Service, Washington, DC, 1984).

[44] R. W. Skaggs, A. Nassehzadeh-Tabrizi, and G. R. Foster, "Subsurface Drainage Effects on Erosion," *Journal of Soil and Water Conservation*, Vol 37, No. 3, pp 167-172.

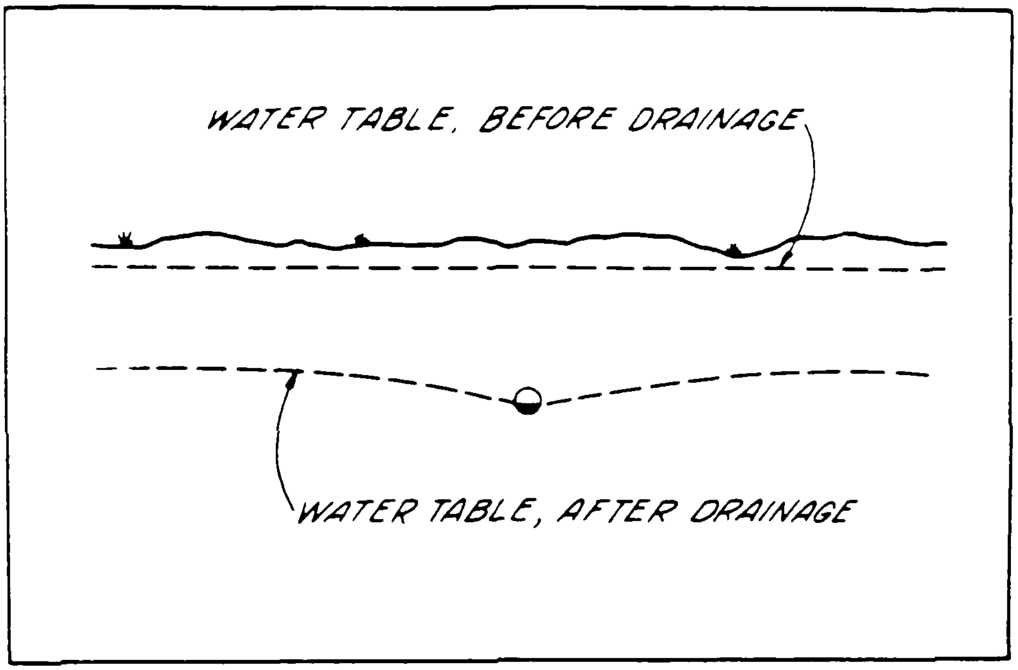

Figure 14. Relief drain lowers water table of low gradient. (Source: *USDA Soil Conservation Service National Engineering Handbook*, Section 16, "Drainage of Agricultural Land" [USDA Soil Conservation Service, Washington, DC, 1971], p 4-53.)

to be drained, the water table's position, level, and annual fluctuation. Drainage systems come in four types: parallel, herringbone, double-main, and random (Figure 15).

Parallel systems have parallel lateral drains located perpendicular to the main drain. This system is used on flat areas having soils of uniform permeability.

The herringbone system has parallel lateral drains that feed into the main at an angle. This system is usually used where the main lies in a depression or in the direction of the major slope. In this case, the gradient of the lateral drains is determined by variation of the angle of confluence with the main.[45]

The double-main system is used where a depression or natural watercourse divides an area to be drained. By placing main drains on either side of the depression or watercourse, ground water is intercepted. The mains provide an outlet for lateral drains which feed into them.

Where the topography is undulating and contains scattered, isolated wet areas, a random system of drains is used. An arrangement of lateral drains and submains for each area may include the parallel or herringbone pattern as needed.

Careful hydrologic investigations, studies, and analyses are needed to plan a subsurface drainage system. Such planning requires the assistance of a professional engineer.

[45] *USDA Soil Conservation Service National Engineering Handbook*, Section 16.

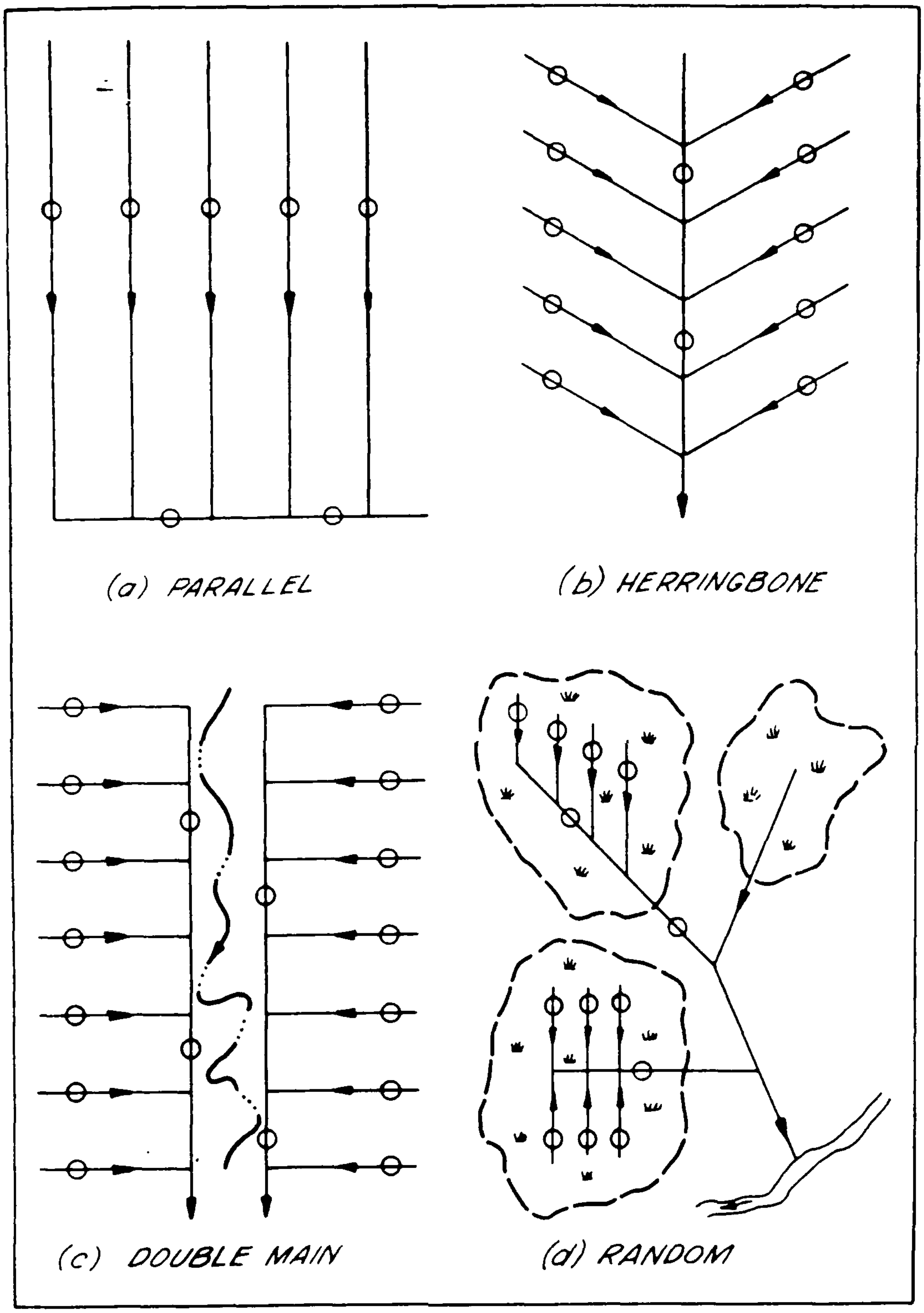

Figure 15. Relief drainage systems for subsurface drainage. (Source: *USDA Soil Conservation Service National Engineering Handbook*, Section 16, "Drainage of Agricultural Land" [USDA Soil Conservation Service, Washington, DC, 1971], p 4-23.)

5 RUNOFF MANAGEMENT

Landforming Measures for Runoff Management

These measures involve mechanical reshaping of the land surface primarily to intercept, divert, convey, retard, or otherwise manage surface runoff. They remove excess water from the land surface by controlling and directing flow to an outlet without causing silting or erosion of the soil.

Terraces

Definition. A terrace is an earth embankment or a ridge and channel constructed across a slope to intercept surface runoff.

Purpose. Terraces reduce erosion by shortening the length of slope and conducting runoff at nonerosive rates to stable outlets. Fitted to the contour of the land, they intercept runoff before it becomes a concentrated flow, and either store it behind the terrace ridge where it is slowly absorbed by the soil or divert it directly to an outlet. Terraces conserve moisture for vegetation, prevent the movement of sheetwash and the formation of rills, assist in gully control by intercepting runoff before it attains eroding velocities, and protect lower lands from flooding and sedimentation.[46]

Conditions for Use. Terracing is most effective as an erosion control practice if each terrace is planned as part of a total system. In planning an effective terrace system, several factors must be considered, including soil characteristics, rainfall, topography, allowable soil loss, the most intensive use expected for the land, and the expected levels of management and maintenance.

The method of runoff disposal distinguishes two major types of terrace systems: (1) gradient terrace systems, which divert runoff, and (2) level terrace systems, which retain it. Since soil characteristics and rainfall are major factors in determining runoff management, they also are major factors in determining which terrace system should be used.[47] Steepness of the land also determines their practicability. Terracing is not advisable on land where the slope is either too slight, too steep, or extremely irregular.

Gradient Terrace Systems. These terraces divert runoff in a graded channel to surface or subsurface outlets. Surface outlets are either constructed waterways or natural, vegetated ones.[48] Subsurface outlets are underground conduits such as tile or pipe drainage systems. While one part of a terrace system might require only a natural, vegetated waterway (Figure 16), it is possible that another part of the same system might have a specific requirement for either surface or subsurface outlets or a combination of both (Figure 17).

Terraces should be properly spaced to shorten slope lengths. Terrace grades should be sufficient to provide adequate surface flow without allowing it to reach erosive velocities. Land smoothing and grading may be needed to improve the effectiveness of the surface drainage. The graded channel collects runoff, transforms it into concentrated flow, and conveys it at a safe velocity by surface waterways or by subsurface outlets.

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[46] *Engineering Field Manual.*
[47] *Engineering Field Manual.*
[48] *Engineering Field Manual.*

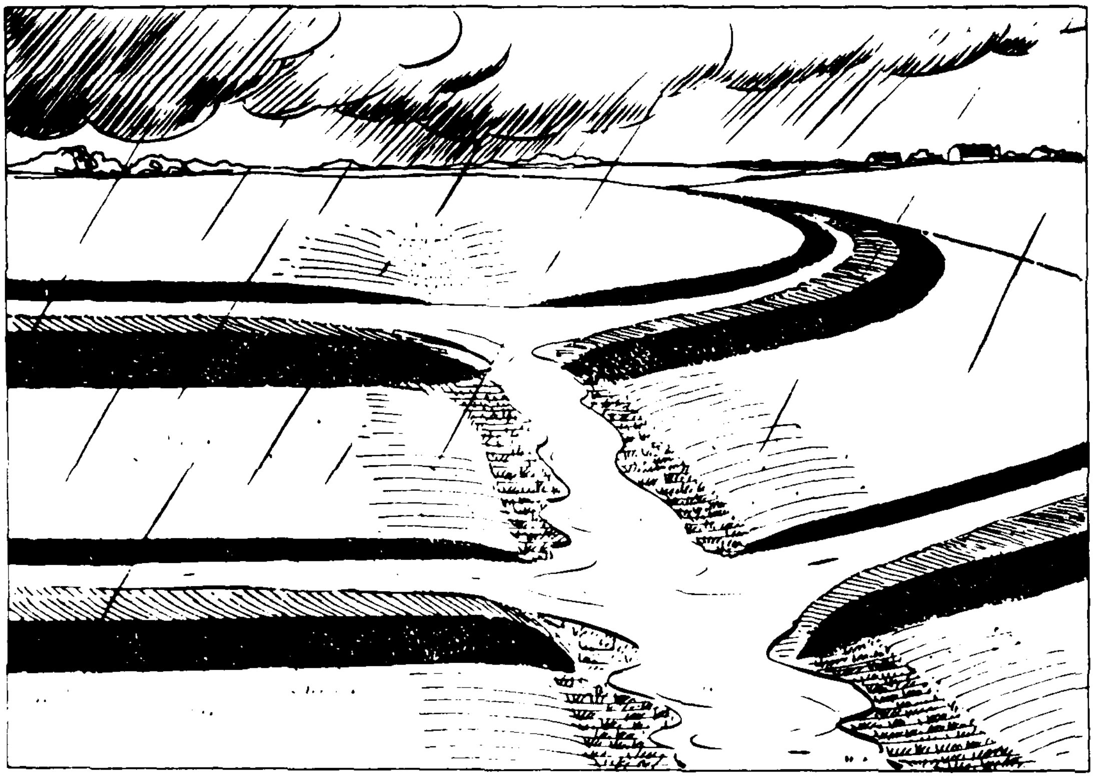

Figure 16. **Gradient terraces with waterway outlets.** (Source: *Engineering Field Manual* [U.S. Department of Agriculture (USDA) Soil Conservation Service, Washington, DC, 1984], p 8-7.)

Level Terrace System. Constructed with no channel grade, these types of systems are designed to store runoff along the terrace for absorption by the soil (Figure 18). They are particularly effective (in suitable soils) where outlets are a problem and runoff from the area must be kept to a minimum or eliminated. It is used in areas of low to moderate rainfall, generally not exceeding a 25- to 30-in. annual average, depending upon soil depth and texture. Terrace ends can be left open, partially open, or closed. A level terrace with complete or partial closure can be used on highly permeable soils which are capable of absorbing the runoff rapidly. In such cases, the soil itself is the outlet. On less permeable soils, the ends of the terrace are left open or partially open. In this case, adequate outlets, either surface or subsurface, must be included to accommodate runoff which cannot be absorbed.[49]

[49]*Engineering Field Manual.*

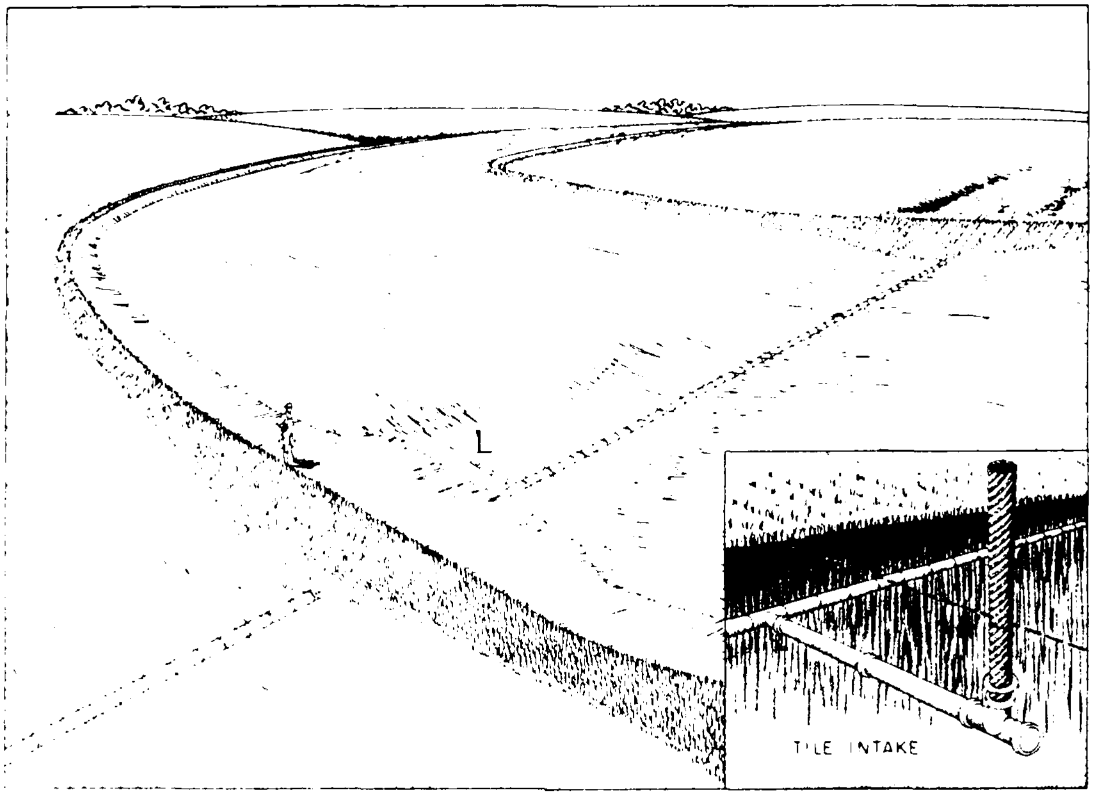

Figure 17. Gradient terraces with underground drainage. (Source: *Engineering Field Manual* [USDA Soil Conservation Service, Washington, DC, 1984], p 8-8.)

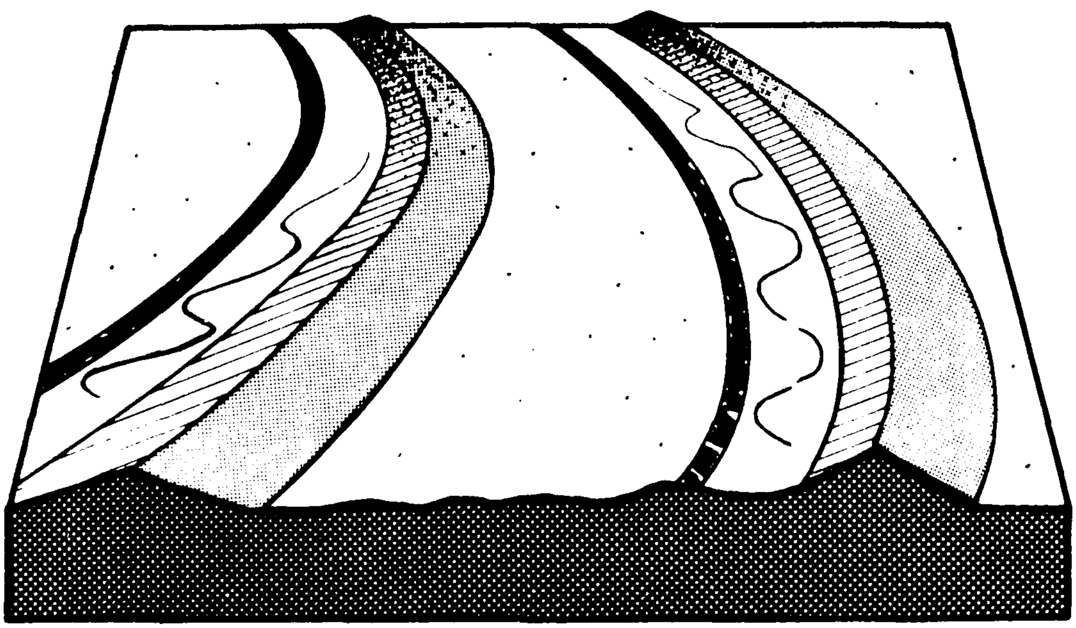

Figure 18. Level terraces.

Benches

Definition. Benches are flat areas constructed by cutting into a slope at intervals.

Purpose. Benching minimizes slope erosion by breaking the length of slope and intercepting and slowing runoff.[50]

Conditions for Use. Benching is frequently done between terraces. The flat plane generally has a width suitable for accommodating maintenance equipment and for placing drainage systems. The bench is generally backsloped to intercept and convey runoff to an appropriate outlet.

Conservation benches are used for moisture control. These are a special type of level terrace constructed with a cut, flat channel which catches runoff, followed by a ridge which controls water impoundment in the channel and the spreading of excess runoff across the next terrace.[51]

Grassed Waterways

Definition. Grassed waterways are natural or constructed waterways that are shaped to required dimensions and vegetated for safe disposal of runoff.[52]

Purpose. Grass-lined waterways and outlets are used to convey runoff at nonerosive rates from natural draws, diversions, terraces or other structures.

Conditions for Use. When rainfall exceeds the rate of water intake by the soil, the resultant runoff must be conveyed at a safe velocity to a stable point of discharge. Waterways are designed with channel dimensions that will carry the estimated flow without damage to the channel or its lining. The soil's resistance to erosion increases with thickness or density of vegetation. Different grasses vary in their resistance to flow, and should be chosen according to flow predicted by the Manning equation, where resistance to flow is expressed as the roughness coefficient.[53]

Grass-lined waterways can be used only in areas where adequate moisture and soil is available for good vegetative growth, and where velocities of flow are not extremely fast. It is important that waterways be free of even small irregularities on the soil surface, so water is not directed into a small, concentrated channel in which the channel velocity will become very high and lead to erosion. Waterways subject to prolonged or constant flow require special treatment with grade control, emplacement of materials, subsurface drainage, or water-conveying structures.

To be effective, a grassed waterway should be built as part of a total conservation program. Except for terracing, corrective measures which may be needed on the land draining into the waterway should be completed prior to constructing the waterway. If terraces are planned to control upland erosion, the grassed waterway which will serve as an outlet for them should be built first in order to provide for the establishment of erosion-resistant vegetation.

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[50] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*
[51] *Engineering Field Manual.*
[52] *Engineering Field Manual.*
[53] J. B. Stall, et al., *Design for a Grassed Waterway*, Circular 1225 (College of Agriculture Cooperative Extension Service, University of Illinois at Urbana-Champaign, 1983).

Level Spreader

Definition. Level spreaders are outlets constructed at zero grade across slopes and at the downstream end of diversions where concentrated, sediment-free runoff may be spread at nonerosive velocities onto an area stabilized by vegetation.[54]

Purpose. Level spreaders convert concentrated flow into sheet flow for disposal at nonerosive velocities.

Conditions for Use. Level spreaders are used where concentrated runoff from unstabilized areas can be diverted to stabilized, vegetated areas (Figure 19). Standards and specifications for level spreaders are set forth by the Soil Conservation Service.[55] Design criteria are determined in accordance with estimated discharge from a 10-year storm (storm of a severity not expected to occur again for 10 years).[56] Construction of the outlet lip must be level and uniform to allow the runoff to spread into sheet flow and to prevent concentrated flow from developing and eroding the stabilized area.

Diversions

Definition. Diversions are ridges or excavated channels, or a combination of both, located across slopes.

Purpose. Diversions reduce the length of long slopes and break up concentrations of water on undulating land surfaces. They direct water away from gullies or other disturbed areas which are particularly vulnerable to erosion processes.

Conditions for Use. Diversions can be constructed across long slopes to reduce length or on gentle slopes and undulating land surfaces in order to break up concentrations of water (Figure 20). Diversions also stabilize soil on slopes by intercepting sheetwash and internal subsurface flow.

Diversions protect terrace systems by diverting headwater from higher terraces. This diversion not only protects the upper terrace from concentrated flows but also protects lowlands from runoff damage.

Ridge Diversions. These are most commonly used at the tops of slopes, along area perimeters, or across disturbed areas. Depending upon their location and function, they are called berms, dikes, diversion dikes, inceptor dikes or perimeter dikes.[57] A ridge of compacted soil or other material prevents the translocation of soil particles downslope in the processes associated with splash, sheet, and rill erosion. Besides controlling these processes, ridge diversions intercept runoff which may also lead to gully erosion. They are often used in combination with channel diversions, which manage concentrated flows of runoff. Ridge diversions constructed with soil brought to the site may be superior to excavated channels in situations where excavation would destroy the natural ground

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Guidelines for Erosion and Sediment Control Planning and Implementation.

Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas.

Nonpoint Source Control Guidance, Construction Activities, NTIS Report No. PB267775 (USEPA, Washington, DC, 1976).

Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.

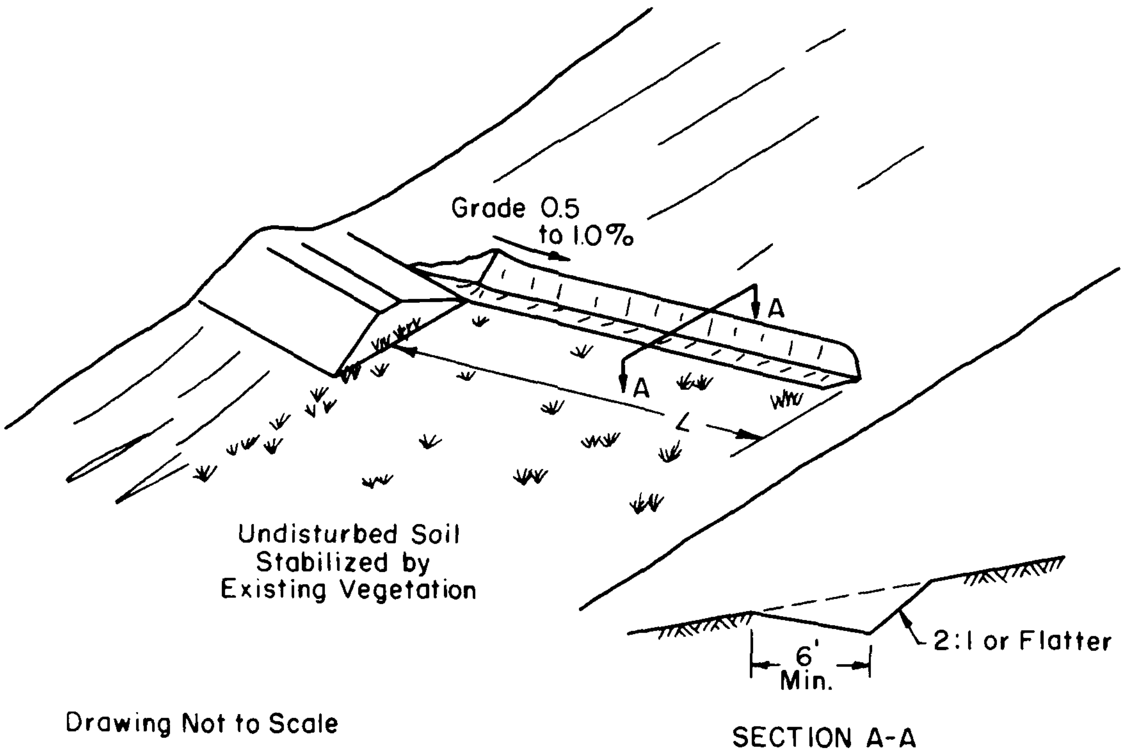

Figure 19. Level spreader construction. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 141.)

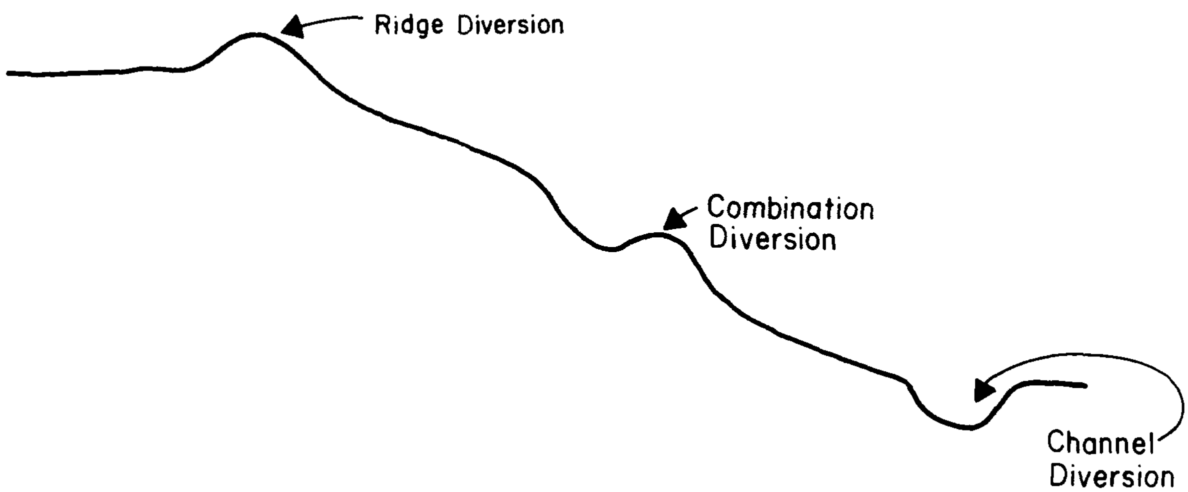

Figure 20. Locations of ridge, combination, and channel diversions.

cover and revegetation is difficult.[58] Specifications and standards for diversion dikes, interceptor dikes, and perimeter dikes are set forth by the Soil Conservation Service.[59]

Channel Diversions. These are also called diversion swales, interceptor swales, perimeter swales, or drainage dips. Excavated diversions are constructed by cutting a ditch into the soil. They can be constructed at the base of hills and slopes where they divert water from low-lying pond areas and improve surface drainage.[60] They can also be used at the tops of slopes where fill is unavailable to construct a ridge diversion. Channel diversions intercept runoff, diverting and collecting it into concentrated channel flow which can then be reduced to nonerosive rates through the use of energy dissipation structures.

Waterbars. A type of channel diversion is the waterbar or cross-road drain. A swale or dike is built diagonally across a sloped roadway to reduce erosion. The slope determines the spacing of waterbars.[61] Drainage from them should not discharge onto sensitive areas.

Combination Diversions. These consist of a constructed ridge and an excavated channel. If soil is used, the material excavated for the channel is used to build the ridge.[62] Combination diversions can be used wherever ridge or channel diversions are appropriate.

Filling and Reshaping

Definition. Filling and reshaping is the elimination of gullied and other severely degraded areas by means of planned earthmoving.

Purpose. The purpose of filling and reshaping is to eliminate gullied and severely degraded areas and to establish vegetation.

Conditions for Use. Filling and reshaping is used to treat gullied and physically degraded areas that require protection from running water. Where practical, a gully should be reshaped to provide stable velocities and other desirable characteristics if used for grassed waterway development.

Since uncompacted material provides little resistance to erosion, the soil must be compacted during the filling process. An entire area rather than small portions should be filled and shaped in order to produce a uniformly smoothed surface that is free of blockages which could produce overfalls and increased erosion from runoff.[63]

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[58] *Design of Roadside Drainage Channels.*

[59] *Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas.*

[60] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*

[61] S. J. Goldman, K. Jackson, and T. A. Bursztynsky, *Erosion and Sediment Control Handbook* (McGraw-Hill Co., New York, 1986).

[62] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*

[63] *Engineering Field Manual.*

Materials for Runoff Management

Materials for runoff management are used in the management of concentrated flows of water which lead to gully, stream, or channel erosion. The materials listed in this section may be used alone, combined with other erosion control measures, or serve as material components in structures. Some materials discussed in this section are also suitable for soil stabilization and have been previously mentioned in the section of this report entitled **Materials for Soil Stabilization.** The following discussions, however, pertain to their applicability as materials for protection against physical land degradation caused by some form of concentrated flow of water (i.e., channel, streambank, runoff).

Manufactured Lining Products

Definition. Linings are flexible coverings, usually available in rolls, which are applied to the soil in drainageways. Many of the materials applied for slope stabilization are also suitable for the protection of slopes and channel banks from concentrated flow.

Purpose. Linings protect channels and drainageways from erosive velocities of concentrated flow until vegetation can be established.

Conditions for Use. Linings are used as temporary measures in unvegetated channels and drainageways where concentrated flow leads to gully erosion and slope instability.

Nettings, Blankets, and Matting. Versatile soil stabilization materials that may also be used in applications on slopes and as channel linings include jute netting and excelsior blankets. A variety of manufactured, synthetic mattings and blankets, when constructed appropriately, are also suitable for this purpose. (See **Materials for Soil Stabilization.**) These products reduce water flow velocities, resulting in less scouring of the soil surface and less sediment transport.

If constructed with a reinforcing weave, the intertwining and durable characteristics of excelsior blankets make them suitable for applications in swales, ditches, and on steep slopes. Likewise, the heavy, rugged construction of jute netting can withstand high runoff velocities, making it suitable for controlling runoff in ditches and swales.

To prevent failure on sites affected by concentrated runoff, nettings, blankets, and mattings must extend laterally to an elevation that is several inches above the anticipated high water flow, and they must be securely fastened to the soil.[64] As required in soil stabilization applications, these materials must have complete contact with the soil to ensure that water does not flow beneath them.

Fiberglass roving. This material provides protection for ditches and drainageways that are subject to erosion by runoff. For use as a channel liner for high velocity waterways, fiberglass roving should be bonded with an asphalt emulsion and should extend upward at least 2 ft above the anticipated high water level.[65] If seed and fertilizer application is planned for the site, it should be completed prior to the fiberglass application.

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[64] *Guidelines for Erosion and Sediment Control Planning and Implementation.*

[65] J. M. Normann, *Design of Stable Channels With Flexible Linings*, Federal Highway Administration Hydraulic Engineering Circular No. 15, NTIS Report No. PB86-184835 (U.S. Department of Transportation, Washington, DC, 1975).

Materials for More Permanent Protection from Runoff

Definition. Durable materials such as riprap, gabions, concrete blocks, flexible mats, and bituminous and concrete products for pavements are generally used for the construction of structures that offer permanent protection from concentrated flows of water.

Conditions for Use. These materials are used where long-term protection against concentrated flow of water is required. The structures in which they are used require some type of maintenance to ensure their long-term effectiveness.

Riprap. This material acts as a protective, erosion-resistant covering on the slopes of embankments, streambanks, at culvert inlets and outlets, on bottoms and side slopes of channel, and at structure foundations. Riprap can be used along the toe of banks to minimize scour, or as a blanket laid over a bank slope to prevent erosion. It is also placed on top of or buried in an eroding bank to stop erosion advancement.[66]

Dumped riprap consists of natural rock or broken concrete dumped in place on a filter blanket or prepared slope. A filter blanket is placed on the bank to prevent the undermining of fine sediment from beneath the riprap protection. Concrete-slab riprap or precast concrete blocks are also types of riprap applications.

On-site fabrication of mortar block forms for slope retaining walls, cribbing, or revetments is another alternative to natural rock riprap protection. These forms are cast by pumping a highly fluid sand/cement mortar into bags or envelopes made of high strength synthetic fiber. These forms can be sized to the dimensions required for particular site conditions.

Gabions. These are rectangular or trapezoidal, multi-celled, wire mesh containers that hold rock. Gabions can be wired together to form monolithic but flexible structures and structural components. They are used as building blocks for a variety of river channel erosion control structures such as revetments, weirs, abutments, and levee facings, and as mats for channel and streambank protection. They are also used for soil stabilization purposes in the construction of retaining walls, chute spillways, box inlets, culvert headwalls, and outlet aprons. Their flexibility is particularly advantageous for use on sites where settlement is expected to occur.[67]

Concrete Block Materials. Standard cellular concrete blocks have been used as protection components for grade stabilization structures in place of concrete slabs or riprap. Blocks are usually underlain with filter fabric, but they may be placed on other suitable filter and bedding material, depending upon the application. They have been used to replace concrete or riprap linings as energy dissipators for slope drains, chute structures, and as aprons for road culverts and storm sewer outlets.[68] The blocks are installed with holes up and filled with gravel or a soil and seed mixture (Figure 21).

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[66]*Streambank Protection Guidelines for Landowners and Local Governments* (U.S. Army Waterways Experiment Station, Vicksburg, MS, 1983).

[67]*Gabions for Erosion Control and Earth Retention* (Maccaferri Gabions, Inc., Dallas, TX, 1984).

[68]L. Wendte and M. E. Andreas, "Concrete Block Lined Chutes and Channel Protection," presented at American Society of Agricultural Engineers (ASAE) Winter Meeting, Chicago, IL, 1986.

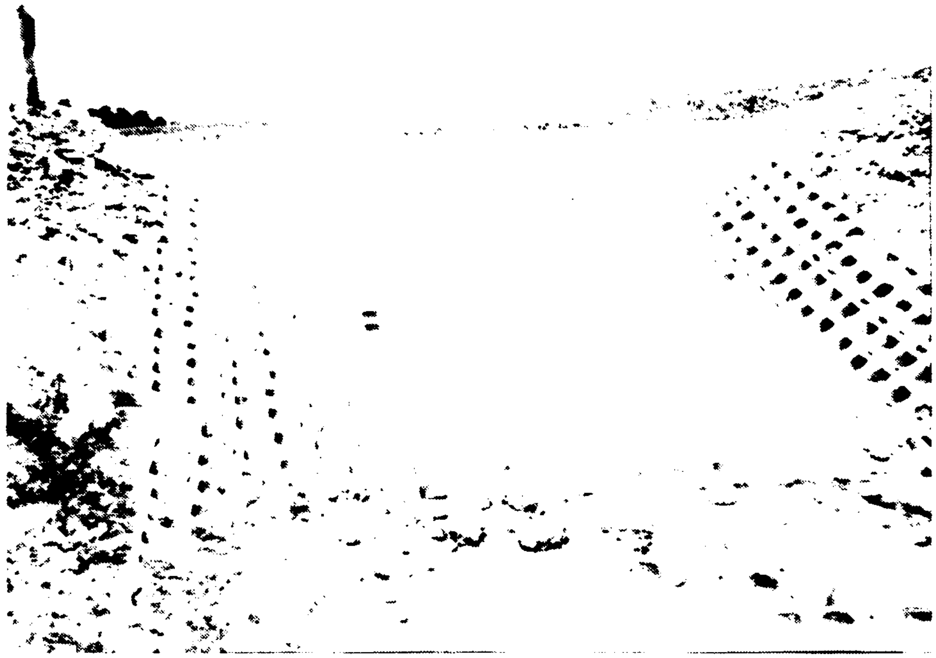

Figure 21. Standard concrete building blocks used in chute structure for management of runoff. (Source: L. Wendte and M. E. Andreas, "Concrete Block Lined Chutes and Channel Protection," presented at American Society of Agricultural Engineers [ASAE] Winter Meeting, Chicago, IL 1986. Used with permission.)

Flexible Mats. These are fabric forms into which mortar is injected under pressure after they are in place.[69] They protect channels that handle concentrated flow from erosive velocities and contribute to shoreline and streambank stabilization. Mats of filterpoint construction articulate along the lines of the filter point, adjusting to minor foundation condition changes and minimizing undercutting.[70] Their uneven surface makes them effective in reducing water velocities.

Concrete and Bituminous Asphalt. These are commonly used for pavements along channels. These products can be used in combination with other materials for the design of composite channel linings. A common design uses grass lined channel sides with a concrete channel bottom. The grass lined sides provide freeboard while the concrete bottom increases the water-carrying capacity of the channel.[71]

During paving operations, dense mixtures rich in asphalt are especially susceptible to plastic flow under the force of gravity when stress application is continuous. Damage from hydrostatic pressure from beneath the pavement also becomes a major consideration. While bituminous linings are more flexible than portland cement linings, they have

[69] *Comparative Costs of Erosion and Sediment Control, Construction Activities*, EPA-430/9-73-016 (USEPA, Office of Water Program Operations, Water Quality and Non-Point Source Control Division, Washington, DC, 1973).
[70] *Guidelines for Erosion and Sediment Control Planning and Implementation.*
[71] J. M. Normann.

less resistance to uplift from hydrostatic pressure and frost action due to their lighter weight and lower strength. (See **Structures and Systems for Soil Stabilization.**)

Structures and Systems for Runoff Management

Structures that control runoff prevent erosion by reducing hydraulic gradients, by conveying or diverting running water from critical areas, or by dissipating energy. These measures manage surface water to avoid gully and channel erosion resulting from concentrated flows.

Grade Stabilization Structures

Definition. Structures that convey water to a lower elevation without causing erosion are called grade stabilization structures.

Purpose. Grade stabilization structures are used to prevent concentrated runoff from reaching erosive velocities and causing channel downcutting as it moves downslope.

Conditions for Use. Grade stabilization structures are used where concentrated flows of water must be conveyed downslope. Due to their permanency and high cost, grade control structures are generally used only where vegetation, diversions, or other measures cannot prevent concentrated water from reaching erosive velocities.

Check dams and drop structures accomplish this by reducing the slope gradient. Chutes, flumes, pipe slope drains, and some spillways are used to divert water from critical areas and safely conduct runoff to lower elevations without reducing gradient. Energy-dissipating outlet protection must be included in the design of these structures.

Check Dams (Weirs). These structures reduce channel erosion by reducing velocities of channel flow. They are used where steep gradients or overfall conditions exist to lower water from one elevation to another. Commonly made with partially lined channel sections and overfall structures, they are constructed from materials such as wood, metal, rock, or gabions (Figure 22).

The drainage area of the channel being protected generally should not exceed 10 acres* except in low-rainfall areas.[72] Check dams should be located in a reasonably straight channel section. Maximum dam height should be approximately 2 ft, with the center at least 6 in. lower than the outer edges. The spacing between dams is determined by dam elevation. Maximum spacing should be such that the base of the upstream dam is at the same elevation as the top of the downstream dam. The channel grade both above and below the structure must be analyzed to determine if erosion or excessive deposition will occur. A formal design is generally required.

Check dams are also used in gully control: they lower the velocity of flowing water by lessening the channel gradient in a series of steps. When initially constructed, the dam slows the flow of water upstream, causing suspended materials to collect in the catch basin behind the dam. Water then flows over the surface formed by these materials at a noneroding gradient. Construction of a series of check dams along a gully creates a stepped channel consisting of a succession of gentle slopes and breaks.

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*1 acre = 0.40 ha.

[72] S. J. Goldman, et al.

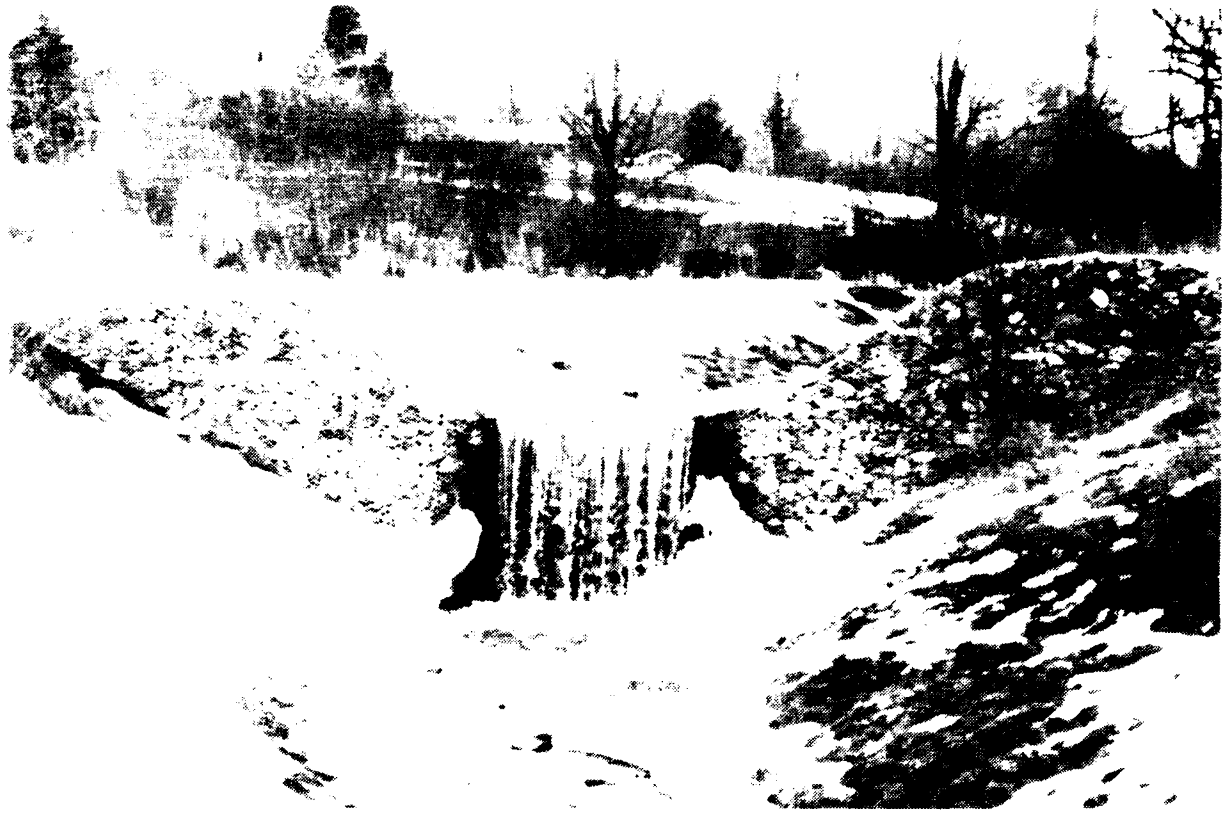

Figure 22. **Gabion check dam (weir).** (Source: Maccaferri Gabions, Inc., Dallas, TX. Used with permission.)

Drop Structures. These control flow by changing the channel slope, hence preventing erosive velocities from developing. Drop or overfall structures are made of rock, concrete, metal, or treated wood. These grade-stabilizing structures safely conduct water to lower elevations at nonerosive velocities in a defended area, where energy is dissipated. Types of drop structures include the straight drop spillway and the box inlet drop spillway. The type and size of structure to be constructed may be determined by the kind of foundation existing at the site.

For gully control, the crest of such structures must be set at an elevation that takes into consideration the upstream movement of the gully head during the healing period. A location for a suitable spillway should also be considered where part of the flow moves through the dam by a principal spillway. Planning and design of these structures normally require the assistance of an engineer.

A straight drop spillway uses a weir structure which allows flow to pass through the weir opening, drop to an apron or stilling basin, and then pass into the downstream channel (Figure 23). It may be constructed of reinforced or plain concrete, rock

Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14 (Federal Highway Administration, Washington, DC, 1983).

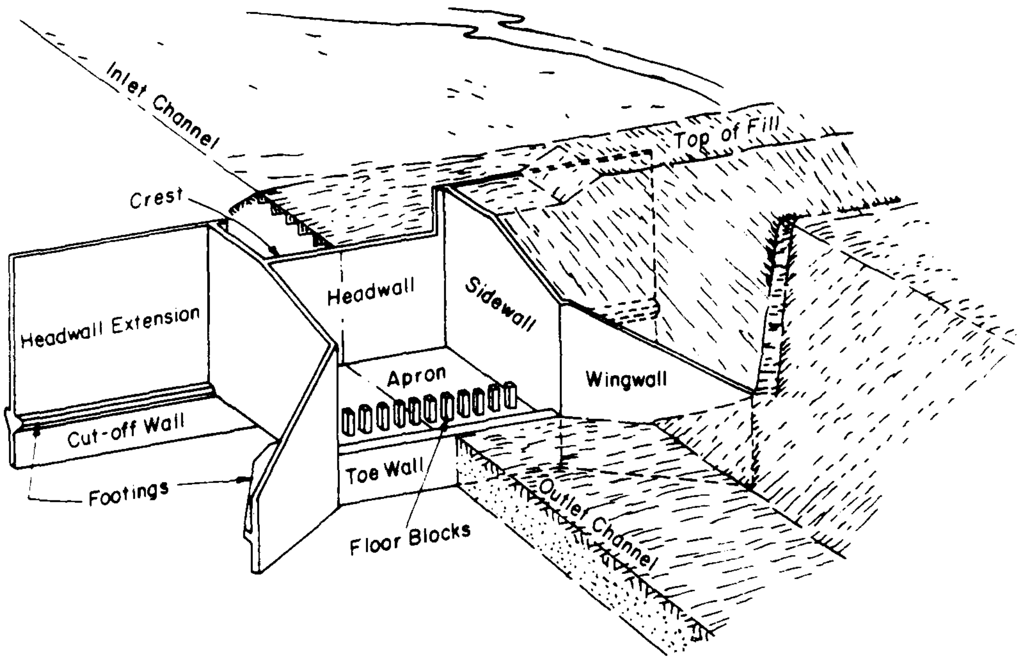

Figure 23. Straight drop spillway. (Source: *Engineering Field Manual* [USDA Soil Conservation Service, Washington, DC, 1984], p 6-2.)

masonry, concrete blocks, or sheet piling of steel, timber, and prefabricated metal. The spillway should be located on a reasonably straight section of channel with no upstream or downstream curves within at least 100 ft of the structure.[74] Foundation material for the structure must have supporting strength, provide resistance to sliding and piping, and be homogeneous to prevent uneven settlement. Its use is limited to overfall heights up to 10 ft.

The box inlet drop spillway is a reinforced concrete box open at the top and at the downstream end. Flow drops down onto the apron and leaves through the open end (Figure 24). The main advantage of the box inlet drop structure is its design for use on open drainage ditches and narrow channels where channel width at the outlet is limited. Its use is limited to overfall heights up to 10 ft.

Drop box (culvert inlet) structures are rectangular box inlet spillways placed at the upstream end of culverts. These structures control grades above culverts and are effective as erosion control measures along roadway ditches.

Continuously Sloped Conveyances. These conveyances safely conduct concentrated flows to lower elevations without reducing the gradient. Energy dissipating structures must be included in their design to reduce erosive velocities that cause erosion at their outlets.

[74] *Engineering Field Manual.*

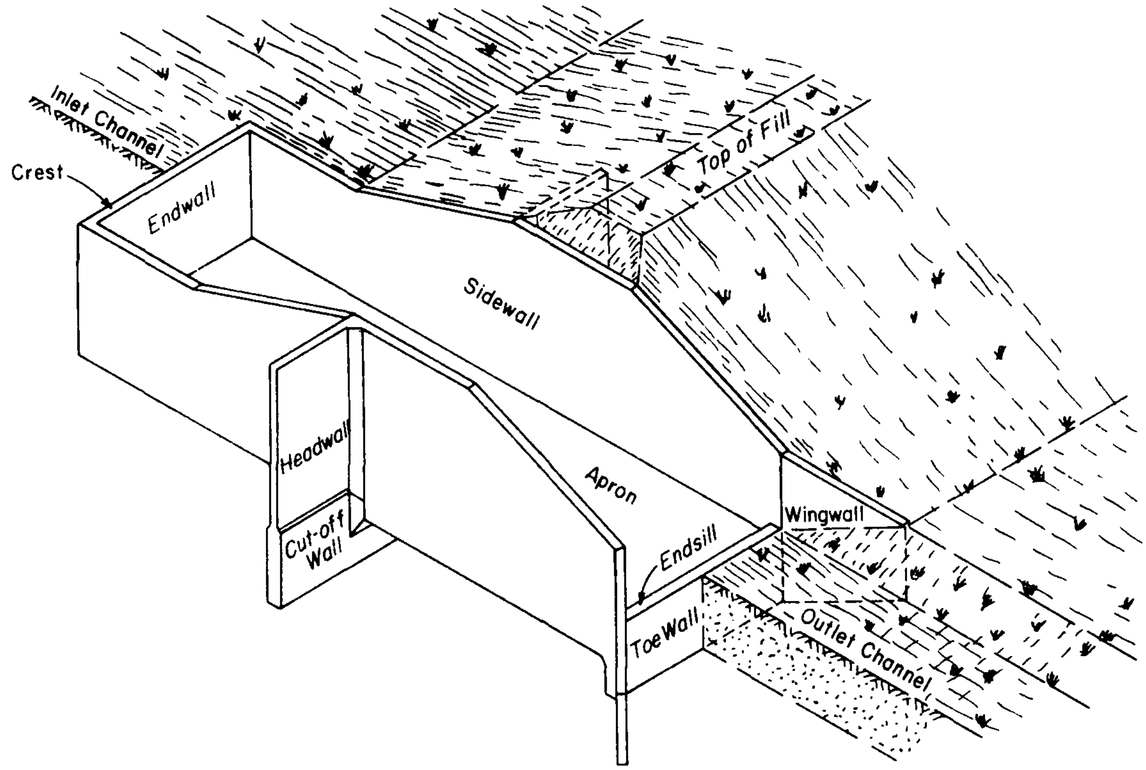

Figure 24. Box inlet drop spillway. (Source: *Engineering Field Manual* [USDA Soil Conservation Service, Washington, DC, 1984], p 6-2.)

A hood inlet can be used to lower surface water into a channel. It consists of a pipe conduit with the inlet end cut at an angle. The long portion of the angular cut, placed on top, forms a hood over the inlet. A plate or antivortex wall is on the upper side of the pipe at the inlet. It can be made of corrugated metal, welded steel, concrete, and other types of pipe (Figure 25).

Drop inlet spillways are designed to carry water under pressure to a lower elevation. They are conduits used to convey runoff through or under an embankment without causing erosion (Figure 26). The barrel may be made of concrete, reinforced concrete, clay or concrete tile, or metal pipe having watertight joints. The riser may be made of reinforced concrete, concrete, pipe, or concrete blocks. Vegetated or earth spillways around at least one end of the embankment should always be used in conjunction with drop inlet structures. Drop inlet should be designed in conjunction with the earth embankment and all other elements of the total structure. Tailwater must be accurately determined since it influences the layout of the spillway outlet and amount of hydraulic head available to produce discharge. It is an efficient structure for the control of relatively high gully heads, generally above 10 ft.[75]

Chutes and flumes are open, permanent, paved conveyances that conduct runoff to lower elevations without causing slope erosion (Figures 27 and 28). In contrast to drop

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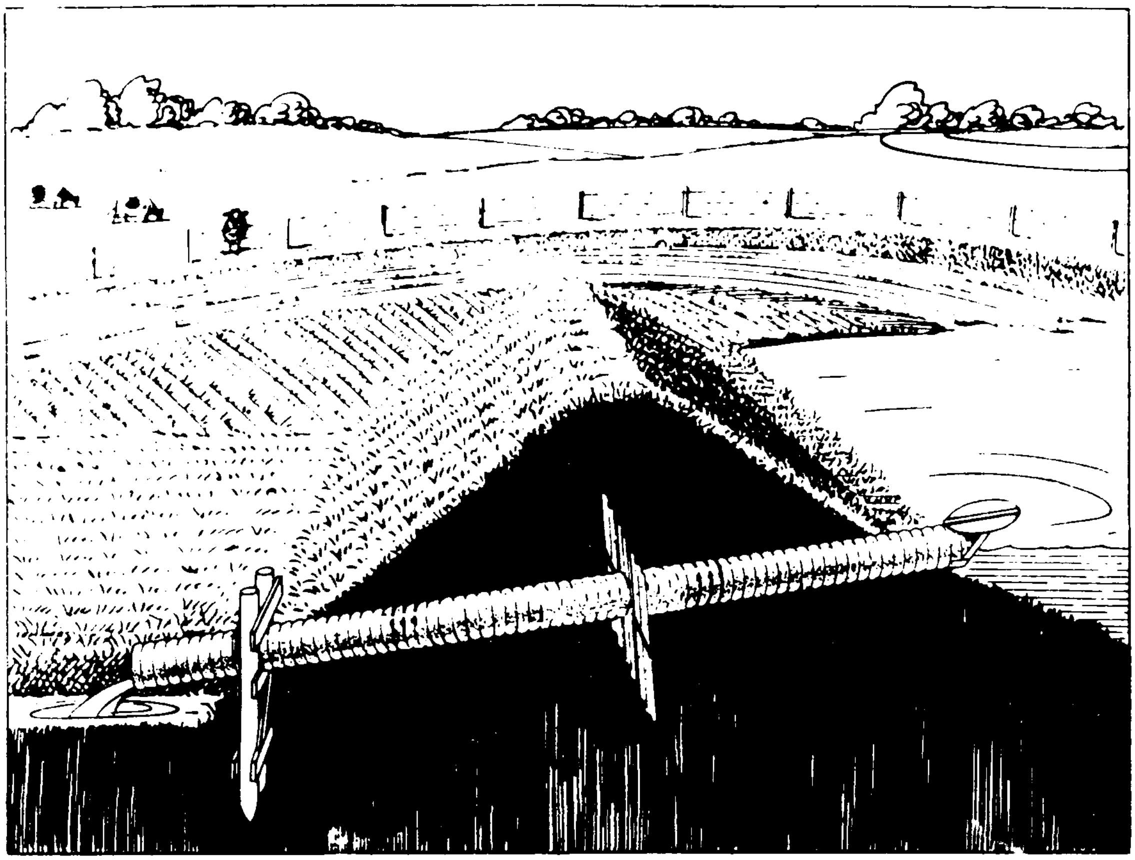
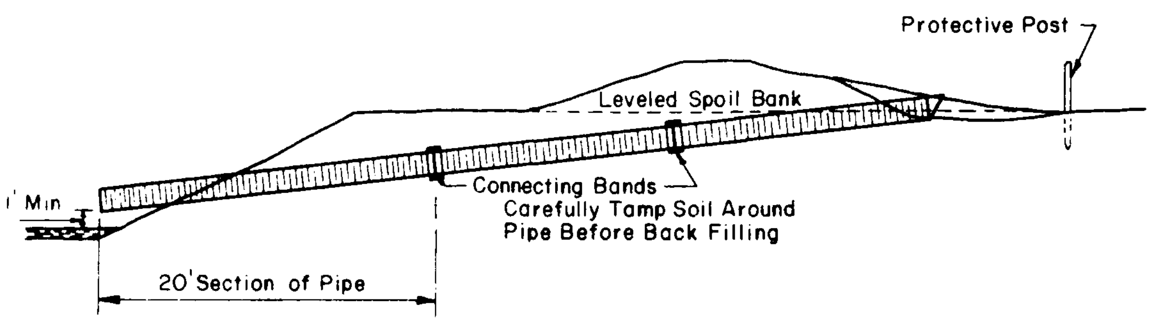
[75] *Engineering Field Manual.*



(a)



(b)

Figure 25. Hood inlet spillways: (a) metal pipe and hood inlet; (b) hood inlet used to convey surface water to channel situated at lower elevation. (Source: *Engineering Field Manual* [USDA Soil Conservation Service, Washington, DC, 1984], p 6-47.)

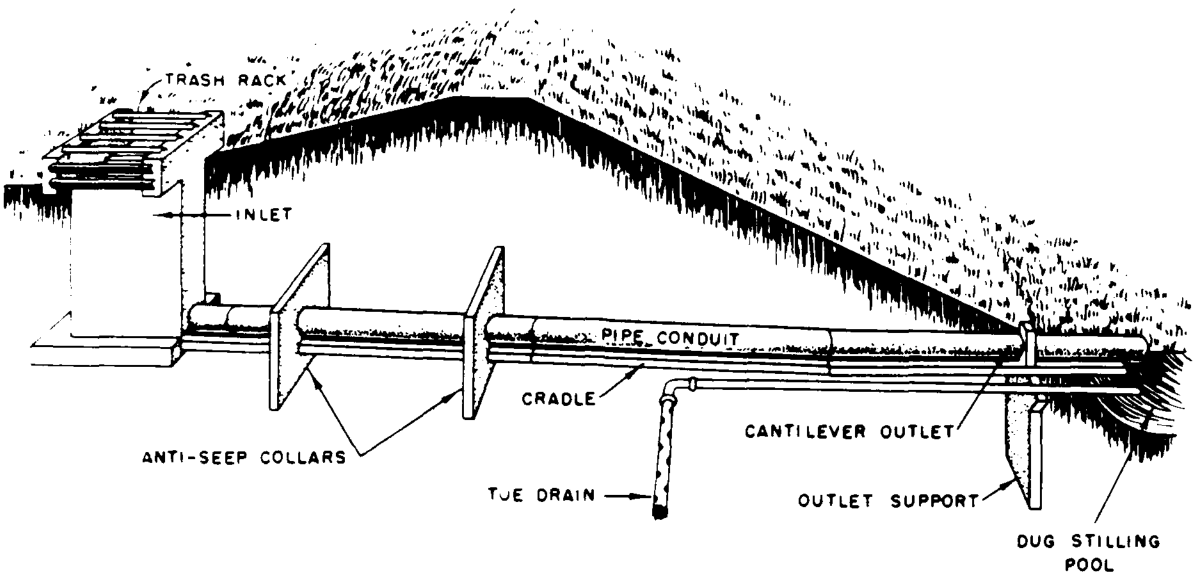


Figure 26. Drop inlet spillway. (Source: *Engineering Field Manual* [USDA Soil Conservation Service, Washington, DC, 1984], p 6-3.)

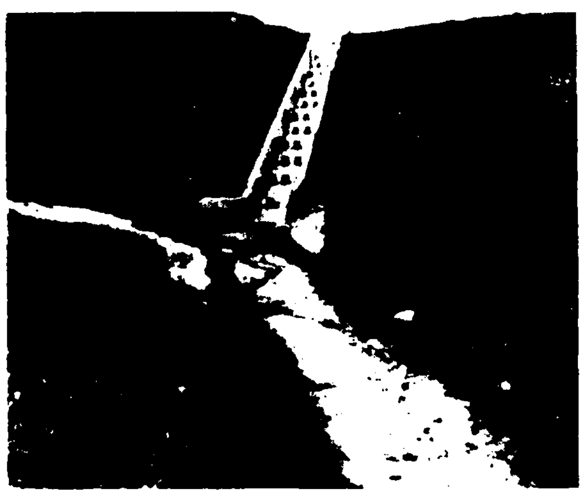


Figure 27. Flume designed with energy dissipators. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 103).

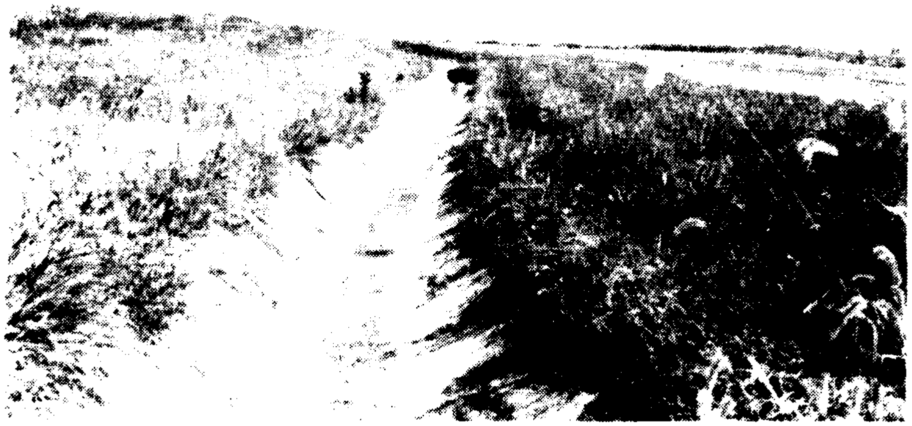


Figure 28. Concrete chute.

structures, chutes and flumes carry water to lower elevations on a continuous slope rather than in a step-wise fashion. As a result, energy dissipating devices must be incorporated into the outlets of the structures at the toes of the slopes.

Pipe slope drains can be constructed with flexible or rigid pipe which can be temporary or permanent. Flexible downdrains can be placed on slopes as temporary measures to conduct storm runoff. Their use protects erosion-susceptible slopes from gully erosion by safely conducting concentrated runoff from one elevation to another. These conduits are made from heavy fabric or other materials. Protection at their outlets must be provided to prevent scour.[76]

Energy Dissipation Structures for Outlet Protection

Definition. Energy dissipators are structures such as stilling basins, wells, and aprons that reduce the kinetic energy and velocity of flowing water.

Purpose. Energy dissipators are used to prevent erosion at outlets and critical areas of erosion where runoff is concentrated. They are used to reduce kinetic energy through turbulence or expansion and redirection of flow. They convert pipe flow to channel flow as well as provide the transition from a paved channel to a natural waterway.[77]

[76] *Guidelines for Erosion and Sediment Control Planning and Implementation.*
[77] S. J. Goldman, et al.

Conditions for Use. Because energy dissipation structures must be carefully selected to accommodate hydraulic conditions and because such structures are generally permanent, they require engineered design.

Stilling basins, wells, and aprons dissipate energy by allowing expansion of flow and by changing momentum that results from redirection of flow.[78] Energy dissipation structures using riprapped aprons, roughness elements, baffles, blocks, and sills allow turbulence to form within a protected area to avoid erosion of soil materials. Riprapped aprons dissipate energy by creating turbulence through the impact of water on the riprap and by spreading on the apron. Sills are located normal to the flow of water at culvert outlets. The length and height of the sill affect flow patterns of jet stream divergence, and hence determine the scouring effects of discharge.[79]

Stilling wells (Figure 29) are commonly used at storm drain and culvert outlets where the use of a riprap blanket or concrete apron is impractical.[80] Stilling basins and wells have designs for particular types of conditions. The St. Anthony Falls (SAF) stilling basin (Figure 30, top) is designed for use with small culverts. The U.S. Bureau of Reclamation Type VI basin (Figure 30, bottom) is an impact-energy dissipator that operates successfully with deficient tailwater.[81] This box-like structure uses a vertical hanging baffle to produce eddies by redirecting the flow of water. Straight drop spillway structures having blocks and sills also serve as energy dissipators. Design procedures for various types of energy dissipators for culverts and channels are provided by the U.S. Federal Highway Administration.[82]

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[78] J. L. Grace and G. A. Pickering, "Evaluation of Three Energy Dissipators for Storm Drain Outlets," Highway Research Record Number 373, *Design of Culverts, Energy Dissipators, and Filter Systems* (Highway Research Board of the National Research Council, National Academy of Sciences, National Academy of Engineering, Washington, DC, 1971).

[79] D. A. Thorson, et al, "Design Criteria for Controlled Scour and Energy Dissipation at Culvert Outlets Using Rock and a Sill," Highway Research Record Number 373, *Design of Culverts, Energy Dissipators, and Filter Systems* (Highway Research Board of the National Research Council, National Academy of Sciences, National Academy of Engineering, Washington, DC, 1971).

[80] J. P. Bohan, *Erosion and Riprap Requirements at Culvert and Storm-Drain Outlets*, Research Report H-70-2 (U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1970).

[81] J. L. Grace and G. A. Pickering.

[82] *Hydraulic Design of Energy Dissipators for Culverts and Channels.*

Figure 29. **Stilling well.** (Source: J. L. Grace and G. A. Pickering, "Evaluation of Three Energy Dissipators for Storm Drain Outlets," Highway Research Record No. 373, *Design of Culverts, Energy Dissipators, and Filter Systems* [National Research Council, National Academy of Sciences, National Academy of Engineering, Washington, DC, 1971], p 54.)

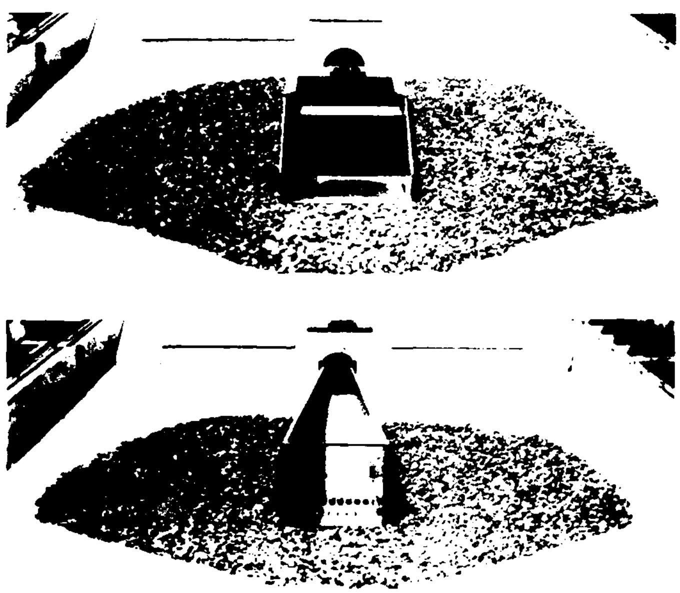

Figure 30. **Stilling basins: U.S. Bureau of Reclamation Type IV design (top), and Saint Anthony Falls design (bottom).** (Source: J. L. Grace and G. A. Pickering, "Evaluation of Three Energy Dissipators for Storm Drain Outlets," Highway Research Record No. 373, *Design of Culverts, Energy Dissipators, and Filter Systems* [National Research Council, National Academy of Sciences, National Academy of Engineering, Washington, DC, 1971], p 54.)

6 SEDIMENT CONTROL

Landforming Measures for Sediment Control

Landforming measures for sediment control range from the construction of small berms that function as filters to sediment retention structures such as traps and basins.

A filter berm is a temporary ridge of crushed rock or gravel constructed across a graded right-of-way[83] to retain sediment by retarding and filtering runoff. Filter berms are ideal for application on sites prior to the establishment of permanent vegetative ground cover. Since the design of their slopes may allow vehicular traffic, they can be constructed across graded right-of-ways.

Sediment retention traps and basins remove and retain part of the sediment being carried by runoff. They do not prevent soil degradation from occurring in the first place. They should be considered only as backup systems to preferred measures that interrupt soil particle detachment and translocation. Structures are classified as traps or basins depending upon size. (See **Structures for Sediment Control.**)

Materials for Sediment Control

Materials for sediment control have structures designed to manage sediment by allowing water to pass through while trapping silt and other fines in strategic locations to keep them from entering storm sewers, conduits, streams, adjacent properties, or areas susceptible to sedimentation damage. Vegetation is also considered here as a living material for sediment control. The materials described below can be incorporated in erosion checks, silt fences, and sediment barriers (see **Structures for Sediment Control**).

Inorganic Materials

Definition. Inorganic filtering materials allow water to pass through them while retaining silt and other fines.

Purpose. These materials are used to trap or prevent the movement of sediment and slow runoff.

Conditions for Use. These materials are incorporated into structures that serve as erosion checks, silt fences, and sediment barriers.

Filter fabrics and meshes, such as jute, burlap, or fiberglass meshes or geotextiles, are materials that impede silt runoff. Filter fabrics typically are available as rolled products. Specification characteristics include weight, grab and burst strength, elongation, resistance to ultraviolet light, and equivalent opening size.

Straw bales, sandbags and gravel are used to construct sediment barriers and dikes that retain sediment and slow storm runoff. Their porous characteristics allow water to pass while retaining fine sediment. Since these materials are usually locally available, their costs relative to manufactured products are small. Their relative effectiveness is controlled by installation procedures and structure maintenance (see **Structures for Sediment Control**).

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[83] *Guidelines for Erosion and Sediment Control Planning and Implementation.*

Organic Materials

Definition. Same as inorganic filtering materials.

Purpose. Same as inorganic filtering materials.

Conditions for Use. Same as inorganic filtering materials.

Vegetation is usually regarded as an ideal soil stabilization and runoff management measure, but it can also serve as a sediment control measure. Vegetative filter strips can trap small amounts of sediment around storm sewer inlets, along streams or along newly established channels. On long slopes, vegetative strips break up and slow overland flow.[34] Tall, dense, sturdy turf makes the best vegetative filter.

Structures for Sediment Control

Sediment control structures range from barriers and fences constructed from a variety of natural, fabricated, or manufactured materials to large sediment retention structures created by landforming methods. Sediment control structures do not stop soil erosion from occurring in the first place. Therefore, these measures should be considered only as backup methods to measures that actually interrupt soil degradation processes.

Sediment Barriers

Definition. Sediment barriers are temporary berms, diversions, or other barriers constructed from strawbales, sandbags, gravel, or manufactured fabrics and meshes, or from a combination of them. (See **Materials for Sediment Control.**)

Purpose. Sediment barriers are constructed to retain sediment by retarding flow and filtering runoff.

Conditions for Use. Sediment barriers are used at storm drain inlets, across minor swales, and in drainageways where temporary use is needed.

Straw Bales. These must be properly entrenched and staked to prevent undercutting and end flow. They are used as a temporary measure at storm drain inlets that do not receive concentrated flow (Figure 31), as dikes at the toe of slopes, and across minor swales and ditches where structural strength is not required. They should not be used across drainageways that carry high-volume or high-velocity flows. When they are used to prevent sediment from entering storm inlet drains, they are placed lengthwise in a trench around the inlet with ends and sides overlapped at corners. After stakes are driven in the bales to anchor them, backfill from the trench is compacted against the bales.

Straw bales and filter fabric or burlap can be used together. Wrapped with fabric, the bales have additional support and filtering capability. Fabric is stapled to the bales and extended into the trench for anchoring.

[34] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*

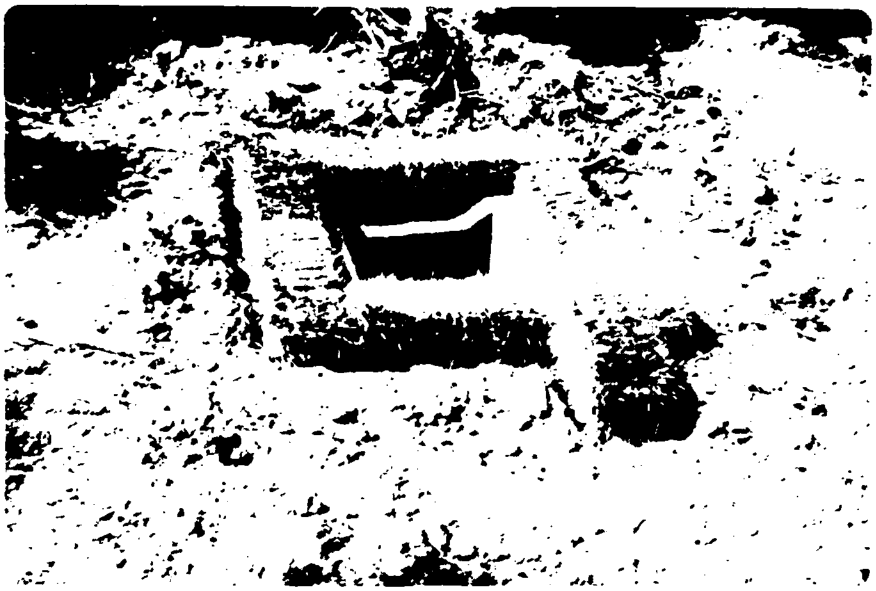


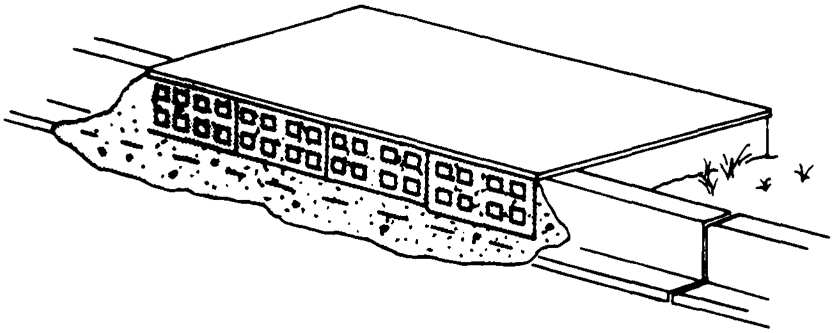
Figure 31. Straw bales used at storm drain inlet. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 160.)

Silt fences. These may be constructed from wire support fence and filter fabric which is commercially available (Figure 32; see **Materials for Sediment Control**). Filtering capability can be controlled by mesh size. Silt fences generally trap a greater percentage of suspended sediments than straw bales used alone.[85] Fencing should be placed along the land contour. In small swales, the fence line should be curved upstream at the sides, directing flow toward the center of the fence. Sides should be higher than the center. Materials should be fastened to the upslope side of the fence posts. Silt fences should not be used in drainageways that carry high-volume or high-velocity flows.

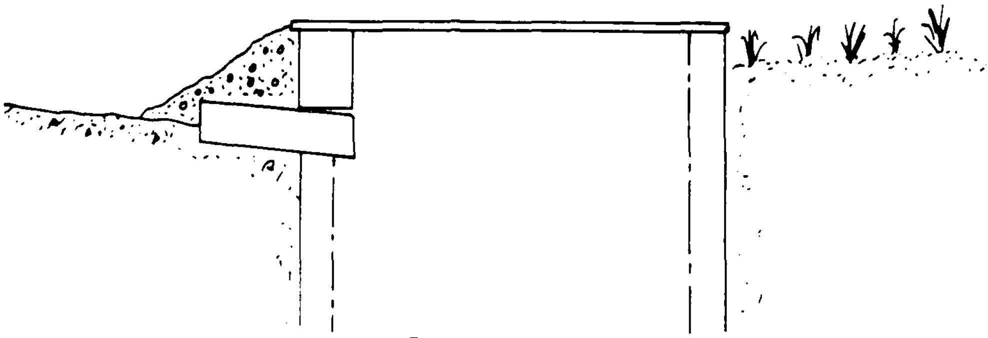
Silt traps can also be made from straw bales if they are stacked and supported by a 12- to 14-gauge wire fence. The bottom row of bales must be entrenched and backfilled as in other sediment barriers. A section of fence without bales should be left to serve as an outlet to relieve water pressure.[86]

Crushed Rock and Gravel Filter Inlets Filter inlets are ridges of crushed rock or gravel constructed at storm drainage inlet structures. They slightly retard and filter runoff before it enters storm drainage systems.[87]

[85] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*
[86] S. J. Goldman, et al.
[87] *Comparative Costs of Erosion and Sediment Control, Construction Activities.*



Isometric



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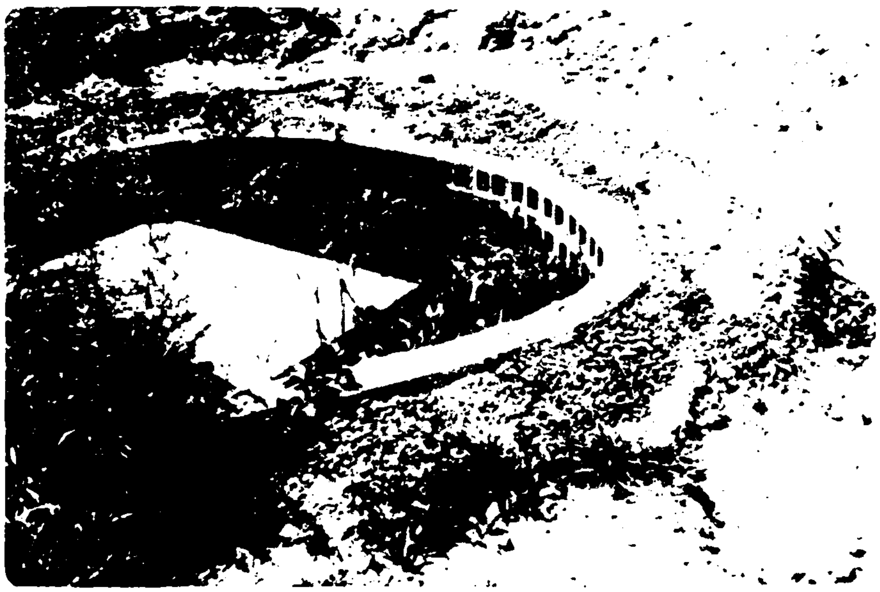

Figure 32. **Filter inlet.** (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [USEPA, Office of Research and Monitoring, Washington, DC, 1972], p 126.)

Sediment Basins

Definition. Sediment basins are constructed by placing a temporary barrier or dam across a drainageway or other appropriate location.

Purpose. Sediment basins are used to trap and retain sediment carried by runoff in order to protect properties and streams located below the basin from sedimentation.

Conditions for Use. Sediment retention structures should be considered only as backups to other measures that interrupt the erosion cycle. Retention structures do not prevent soil degradation from taking place.

Sediment trapping efficiency depends upon the soil type of the watershed. Suspended clay and silt particles do not settle quickly. As a result, watersheds containing soils high in clay and silt require large basins. Sediment retention structures typically are designed with a removal efficiency of only 50 to 75 percent. Even if design performance is realized, up to half of the eroded soil reaching the trap or basin will pass through it.[88] The construction of sediment basins requires formal engineering design. Standards and specifications for sediment basins are provided by the Soil Conservation Service.[89]

Sediment Traps

Definition. Sediment traps are small, temporary basins constructed by excavation and/or an embankment.

Purpose. Sediment traps are used to trap and retain sediment carried by runoff in order to protect properties and streams located below the sediment trap.

Conditions for Use. Sediment traps retain sediment from drainage areas smaller than 5 acres and have embankments no greater than 5 ft in height. The trap should not be located where it will collect clean water from a stream or clean runoff.

Excavated traps are generally located at low points on a site where a pit is dug to collect and hold runoff. This type of structure is also used at sites where natural valleys and depressions do not exist or where the drainage area is small.[90] A disadvantage of excavated traps and basins built in poorly drained soils is the intrusion of ground water.

A combination excavated and embankment type of trap is most applicable on gently to moderately sloped sites where slight natural depressions exist (Figure 33). Excavated materials from the pit are used to construct the embankment.[91] Standards and specifications for sediment traps are provided by the USDA Soil Conservation Service.[92]

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[88] S. J. Goldman, et al.

[89] *Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas.*

[90] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*

[91] *Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois.*

[92] *Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas.*

Figure 33. Sediment retention structure. (Source: *Guidelines for Erosion and Sediment Control Planning and Implementation*, EPA-R2-72-015, U.S. Environmental Protection Technology Series [U.S. Environmental Protection Agency, Office of Research and Monitoring, Washington, DC, 1972], p 156.)

7 CONCLUSION

The methods, materials, structures, and systems described in this report reflect state-of-the-art technologies and measures for erosion control. They have been categorized and presented on the basis of how their use disrupts the phases of the erosion process. It is recommended that the reader approach the problem of erosion and physical degradation on Army training lands from this perspective in order to select appropriate technologies and methods that restore the land and prevent future degradation.

To familiarize the reader with current erosion control technologies, this report has itemized, defined, and briefly discussed a variety of them. For more detailed discussions of conditions for use, engineering standards, specifications, and design, the reader must consult the appropriate references.

Research is currently underway to develop guidance for land evaluation methods which will help the planner and trainer identify problems, assess needs, and select cost-effective erosion control measures.

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